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Vol. 3

Addendum to
Structural Arrangement Trade Study

Reusable Hydrogen Composite Tank System (RHCTS)
and
Graphite Composite Primary Structures (GCPS)

Cooperative Agreements NCC8-39 and NCC1-193

March 14, 1995

Prepared for:
NASA
Marshall Space Flight Center
Langley Research Center
Ames Research Center

NASA | Rockwell Aerospace Space Systems Division | NORTHROP GRUMMAN | Rockwell Aerospace North American Aircraft | HERCULES

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Vehicle Resizing Charts

NRA Trades

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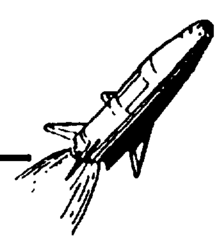
WEIGHTS (lb)														
AIRFRAME	115,259	119,234	119,627	123,774	114,708	127,217	120,816	132,484	121,192	128,728	122,828	137,046	123,468	120,195
• Control Surfaces Str	27,728	28,304	29,056	29,668	27,648	29,437	28,733	30,412	28,788	31,855	30,918	39,596	30,163	28,980
wing str	20,961	21,396	22,134	22,600	20,900	22,252	21,769	23,041	21,810	24,614	23,890	32,067	22,060	22,038
tail str	5,271	5,381	5,392	5,505	5,256	5,596	5,425	5,742	5,435	5,640	5,474	5,884	6,543	5,408
canard	0	0	0	0	0	0	0	0	0	0	0	0	0	0
body flap	1,496	1,527	1,530	1,562	1,492	1,588	1,540	1,630	1,543	1,601	1,554	1,664	1,560	1,535
Speed Brake	0	0	0	0	0	0	0	0	0	0	0	0	0	0
• Primary Structure	52,874	56,473	55,243	58,975	53,494	64,321	57,148	61,846	58,350	59,561	57,703	62,082	57,959	56,958
Forward Fuselage	1,685	1,720	1,723	1,759	1,680	2,104	1,613	1,708	1,616	1,677	1,628	1,744	1,635	1,608
Payload Section	8,986	9,163	9,502	9,692	9,745	9,952	12,044	13,856	13,153	12,498	12,149	12,968	12,197	12,008
P/L prov	3,782	3,782	3,782	3,782	3,782	3,782	3,782	3,782	3,782	3,782	3,782	3,782	3,782	3,782
Lh2 Tank	9,947	12,619	10,219	12,967	9,913	8,543	11,159	11,940	11,184	11,689	11,280	12,244	11,337	11,117
O2 tank	11,824	12,131	11,444	11,745	11,782	12,738	10,639	11,418	10,664	11,168	10,760	11,722	10,816	10,597
RP tank	1,357	1,393	1,396	1,433	1,352	1,462	1,407	1,510	1,411	1,477	1,424	1,551	1,431	1,402
Outer Shell (Non Int Lh2 Tan	0	0	0	0	0	9,337	0	0	0	0	0	0	0	0
Body Fairings	3,476	3,549	4,935	5,039	3,466	3,691	4,369	4,624	4,377	4,543	4,409	4,723	4,427	4,355
Carry Thru & Attach	3,295	3,363	3,370	3,441	3,286	3,498	3,391	3,589	3,397	3,526	3,422	3,666	3,436	3,380
Thrust Str	8,521	8,753	8,871	9,116	8,488	9,214	8,744	9,419	8,766	9,202	8,849	9,683	8,897	8,708
• TPS	31,283	31,023	31,889	31,631	30,200	29,909	31,477	36,598	30,591	33,738	30,524	31,675	31,850	30,808
ACC	3,125	3,180	3,185	3,242	3,117	3,287	3,202	3,360	3,207	3,309	3,227	3,420	3,238	3,193
AETB	5,780	5,882	5,892	5,997	5,766	6,081	5,871	6,160	5,880	6,068	5,414	4,673	5,937	5,547
AFRSI	11,006	11,078	11,219	11,294	10,766	11,529	11,754	8,894	11,637	11,058	11,637	11,429	11,963	11,447
TABI	8,246	8,867	8,405	9,040	7,434	7,318	7,765	5,475	6,977	6,636	7,339	6,858	7,794	7,745
Carbon Silicone	0	0	0	0	0	0	0	9,677	0	3,683	0	2,207	0	0
Cryo Insulation	3,125	2,017	3,188	2,058	3,117	1,694	2,884	3,032	2,889	2,985	2,908	3,089	2,918	2,876
•Miscellaneous	3,374	3,434	3,439	3,501	3,366	3,550	3,457	3,628	3,463	3,573	3,484	3,693	3,496	3,448
purge & vent	1,153	1,173	1,175	1,196	1,150	1,213	1,181	1,239	1,183	1,221	1,190	1,262	1,194	1,178
Thermal Control	2,222	2,261	2,265	2,305	2,216	2,337	2,276	2,389	2,280	2,353	2,294	2,432	2,302	2,270
PROPULSION	74,623	76,654	76,855	78,974	74,342	80,673	77,874	83,864	78,067	81,936	78,805	86,204	79,236	77,555
engines	45,503	46,747	46,870	48,166	45,331	49,204	47,270	50,919	47,388	49,745	47,837	52,345	48,100	47,076
Engine Flt Cont	5,452	5,601	5,615	5,771	5,431	5,895	5,660	6,097	5,675	5,957	5,728	6,268	5,760	5,637
prop and pres	15,161	15,576	15,617	16,049	15,104	16,394	16,189	17,439	16,229	17,036	16,383	17,927	16,473	16,122
OMS thrusters	2,862	2,937	2,944	3,022	2,852	3,086	2,968	3,187	2,975	3,117	3,002	3,273	3,018	2,957
ACS	3,174	3,257	3,265	3,352	3,163	3,422	3,292	3,535	3,300	3,457	3,330	3,630	3,347	3,279
OMS tank	2,470	2,538	2,544	2,615	2,461	2,671	2,494	2,687	2,500	2,625	2,524	2,762	2,538	2,484
SUBSYSTEMS	19,328	19,656	19,689	20,029	19,283	20,305	19,800	20,752	19,831	20,447	19,949	21,121	20,018	19,749
avionics	1,855	1,855	1,855	1,855	1,855	1,855	1,855	1,855	1,855	1,855	1,855	1,855	1,855	1,855
Env Cont - Active	1,411	1,430	1,431	1,450	1,409	1,465	1,437	1,489	1,439	1,472	1,445	1,509	1,449	1,434
Power Dist	3,196	3,237	3,241	3,284	3,190	3,318	3,254	3,371	3,257	3,334	3,272	3,416	3,281	3,247
Power Generation	1,283	1,300	1,302	1,319	1,281	1,332	1,307	1,354	1,308	1,339	1,314	1,372	1,318	1,304
Mechanical Systems	3,521	3,567	3,571	3,618	3,515	3,656	3,585	3,715	3,589	3,673	3,605	3,764	3,615	3,578
landing gear	7,922	8,128	8,148	8,363	7,893	8,540	8,223	8,829	8,243	8,634	8,317	9,065	8,361	8,191
range safety	140	140	140	140	140	140	140	140	140	140	140	140	140	140
SUB TOTAL	209,210	215,544	216,170	222,778	208,333	228,194	218,489	237,100	219,090	231,111	221,382	244,372	222,722	217,499
margin	31,382	32,332	32,426	33,416	31,250	34,229	32,773	35,565	32,864	34,667	33,207	36,656	33,408	32,625
EMPTY WEIGHT	240,592	247,876	248,596	256,193	239,583	262,423	251,263	272,666	251,954	265,778	254,589	281,028	256,130	250,123
Misc (Frost,Buoyancy etc)	1,374	1,374	1,374	1,374	1,374	903	1,347	1,347	1,347	1,347	1,347	1,347	1,347	1,347
payload	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
DRY WEIGHT	266,966	274,250	274,970	282,567	265,957	288,326	277,610	299,013	278,301	292,125	280,936	307,375	282,477	276,470
propellant	2,480,686	2,548,475	2,555,175	2,625,874	2,471,293	2,682,799	2,576,734	2,775,672	2,583,155	2,711,648	2,607,654	2,853,401	2,621,975	2,566,143
GLOW	2,747,652	2,822,725	2,830,145	2,908,441	2,737,250	2,971,125	2,854,344	3,074,685	2,861,456	3,003,773	2,888,590	3,160,776	2,904,452	2,842,613

Case	15	16	17	18	19	20	21	22	24	25	26
Configuration	2A-1 CS-14	2A-2	2A-3	2A-3 W-11	2B-1	2B-1-OTF5	3A-1	3A-2	4A-1	4A-2	3A1M
WEIGHTS (lb)											
AIRFRAME	**123,476**	**121,776**	**127,286**	**132,831**	**136,352**	**143,763**	**118,785**	**124,931**	**126,137**	**134,398**	**123,868**
• Control Surfaces Str	**30,799**	**28,872**	**31,620**	**34,528**	**30,373**	**31,401**	**29,420**	**30,334**	**27,818**	**28,932**	**30,197**
wing str	23,742	21,874	24,429	27,145	22,879	23,653	20,576	21,216	20,605	21,430	21,120
tail str	5,497	5,451	5,601	5,751	5,838	6,035	5,321	5,487	5,619	5,844	5,462
canard	0	0	0	0	0	0	2,012	2,074	0	0	2,065
body flap	1,580	1,547	1,590	1,632	1,657	1,713	1,510	1,557	1,595	1,659	1,550
Speed Brake	0	0	0	0	0	0	0	0	0	0	0
• Primary Structure	**57,961**	**58,726**	**59,692**	**62,839**	**70,374**	**72,889**	**55,986**	**61,354**	**62,625**	**69,004**	**58,154**
Forward Fuselage	1,635	1,621	1,666	1,710	1,736	1,795	1,605	1,655	2,196	2,284	1,647
Payload Section	12,197	12,099	12,749	13,072	13,408	13,838	7,911	8,144	15,072	14,241	8,109
P/L prov	3,782	3,782	3,782	3,782	3,782	3,782	3,472	3,472	4,712	4,712	3,472
Lh2 Tank	11,337	12,507	10,184	11,964	8,894	9,253	10,141	13,421	12,965	17,622	8,718
O2 tank	10,817	10,703	11,071	11,441	11,655	12,147	15,176	15,770	13,978	14,677	13,424
RP tank	1,431	1,416	1,465	1,514	1,542	1,607	1,703	1,770	1,471	1,544	1,760
Outer Shell (Non Int Lh2 Tan	0	0	0	0	9,790	10,121	0	0	0	0	4,545
Body Fairings	4,428	4,390	5,944	6,103	4,896	5,062	3,687	3,801	0	1,979	3,784
Carry Thru & Attach	3,436	3,407	3,501	3,595	3,649	3,772	3,328	3,430	3,741	3,653	3,414
Thrust Str	8,898	8,800	9,330	9,658	11,022	11,511	8,965	9,892	8,491	8,292	9,280
• TPS	**31,218**	**30,706**	**32,421**	**31,831**	**31,926**	**35,889**	**30,526**	**30,314**	**32,132**	**32,779**	**32,399**
ACC	3,238	3,215	3,290	3,364	3,407	3,505	4,362	4,477	3,299	3,410	4,459
AETB	4,952	5,895	6,032	5,845	6,134	5,955	6,079	6,238	5,967	6,169	6,214
AFRSI	11,608	11,772	12,154	12,134	12,362	10,552	10,506	10,853	11,156	11,527	11,336
TABI	7,854	7,797	7,979	7,652	7,871	7,076	7,309	7,655	8,865	10,232	8,067
Carbon Silicone	649	0	0	0	0	6,385	0	0	0	0	0
Cryo Insulation	2,918	2,027	2,967	3,036	2,153	2,216	2,270	1,091	2,845	1,440	2,323
•Miscellaneous	**3,496**	**3,471**	**3,552**	**3,633**	**3,679**	**3,784**	**2,854**	**2,929**	**3,562**	**3,682**	**2,918**
purge & vent	1,194	1,186	1,213	1,241	1,257	1,293	1,162	1,192	1,217	1,258	1,188
Thermal Control	2,302	2,286	2,339	2,392	2,422	2,492	1,692	1,737	2,345	2,424	1,730
PROPULSION	**79,240**	**78,367**	**81,196**	**84,042**	**85,445**	**89,229**	**74,731**	**77,800**	**83,323**	**87,703**	**77,679**
engines	48,102	47,571	49,294	51,028	52,030	54,341	46,201	48,106	49,504	52,115	47,820
Engine Flt Cont	5,760	5,696	5,903	6,110	6,230	6,507	5,532	5,760	5,928	6,241	5,726
prop and pres	16,474	16,292	16,882	17,476	17,575	18,356	14,452	15,048	18,716	19,704	15,298
OMS thrusters	3,018	2,986	3,090	3,194	3,255	3,393	2,904	3,018	3,102	3,259	3,001
ACS	3,347	3,312	3,427	3,542	3,610	3,764	3,221	3,347	3,440	3,614	3,328
OMS tank	2,538	2,510	2,601	2,692	2,746	2,868	2,421	2,521	2,632	2,771	2,506
SUBSYSTEMS	**20,018**	**19,879**	**20,330**	**20,780**	**21,043**	**21,637**	**19,507**	**20,007**	**20,383**	**21,060**	**19,932**
avionics	1,855	1,855	1,855	1,855	1,855	1,855	1,855	1,855	1,855	1,855	1,855
Env Cont - Active	1,449	1,441	1,466	1,490	1,504	1,536	1,420	1,447	1,469	1,505	1,443
Power Dist	3,281	3,263	3,319	3,375	3,406	3,478	3,215	3,277	3,326	3,409	3,268
Power Generation	1,318	1,311	1,333	1,355	1,368	1,397	1,291	1,316	1,336	1,369	1,312
Mechanical Systems	3,615	3,596	3,658	3,719	3,753	3,833	3,542	3,611	3,665	3,756	3,600
landing gear	8,361	8,273	8,559	8,847	9,015	9,399	8,045	8,361	8,593	9,026	8,314
range safety	140	140	140	140	140	140	140	140	140	140	140
SUB TOTAL	**222,734**	**220,021**	**228,811**	**237,654**	**242,840**	**254,629**	**213,023**	**222,738**	**229,843**	**243,159**	**221,279**
margin	33,410	33,003	34,322	35,648	36,426	38,194	31,953	33,411	34,476	36,474	33,192
EMPTY WEIGHT	**256,144**	**253,024**	**263,133**	**273,302**	**279,266**	**292,824**	**244,977**	**256,149**	**264,319**	**279,633**	**254,471**
Misc (Frost,Buoyancy etc)	1,347	1,347	1,347	1,347	1,070	1,070	1,390	1,390	1,497	1,497	1,390
payload	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
DRY WEIGHT	**282,491**	**279,371**	**289,480**	**299,649**	**305,336**	**318,894**	**271,367**	**282,539**	**290,816**	**306,130**	**280,861**
propellant	2,622,099	2,593,106	2,687,065	2,781,584	2,836,397	2,962,419	2,518,400	2,622,246	2,698,430	2,840,775	2,606,648
GLOW	**2,904,590**	**2,872,477**	**2,976,545**	**3,081,233**	**3,141,733**	**3,281,313**	**2,789,767**	**2,904,785**	**2,989,246**	**3,146,905**	**2,887,509**

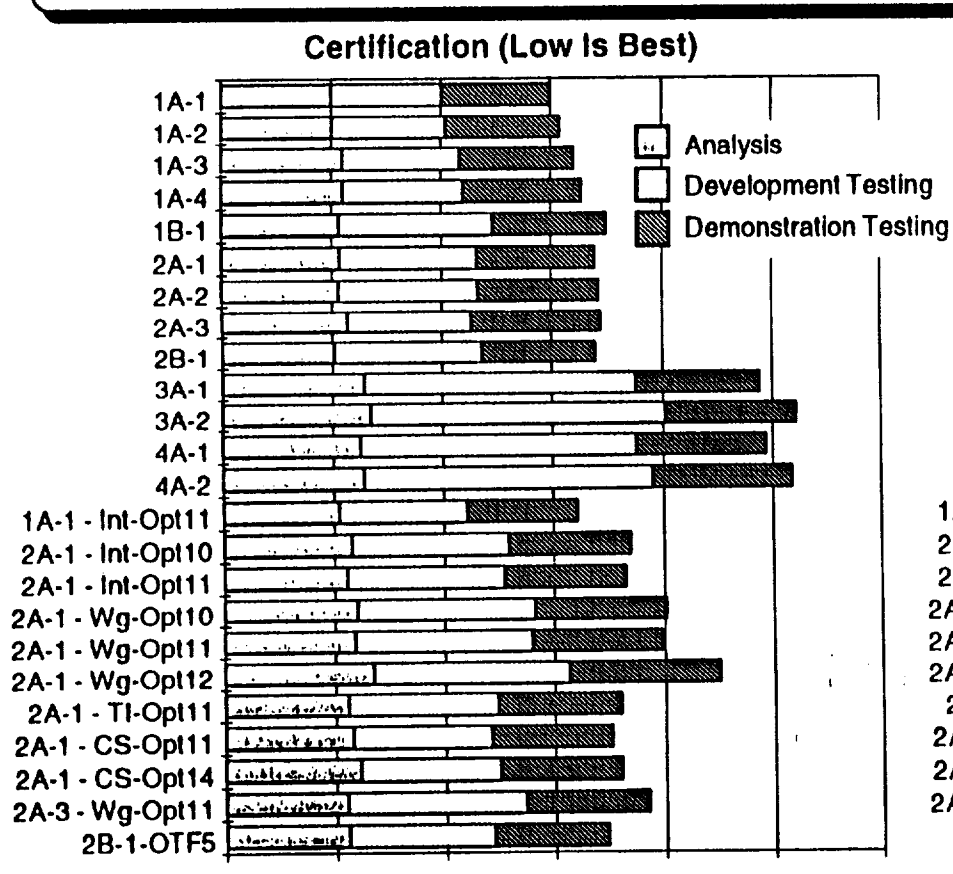
Selection Criteria and Back-up Charts

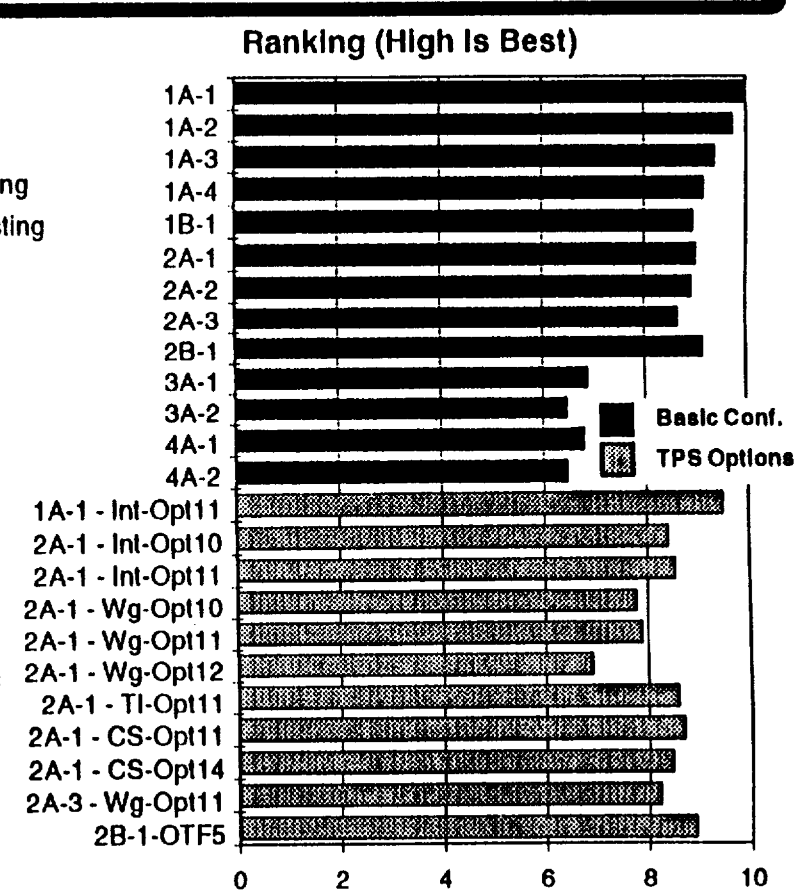
1A Option Ranked Best For Certification Effort



SSTO

1a. Certification Effort - (Qualitative evaluation) - The candidate vehicle options are rated according to the perceived effort of analysis, development testing, and demonstration testing required for certification of structure and TPS. Certification refers to only the design and is achievable without fabrication of a vehicle.





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SC-1a-1 Certification Analysis

Option	LO tank	Wght	RP tank	Wght	Inter-tank	Wght	LH2 Tank	Wght	LH2 tank outer shell	Wght	Wing	Wght	Fairings	Wght	Canard	Wght	Thrust struct	Wght	Aft Skirt	Wght	Tail	Wght	Total score
1A-1	1.25	1.08	1	0.13	1	0.85	2	0.94	0	0	1	1.99	1.25	0.33	0	0	1	0.61	1.25	0.18	1	0.5	7.94
1A -2	1.25	1.08	1	0.13	1	0.85	1.75	1.11	0	0	1	1.99	1.25	0.33	0	0	1	0.61	1.25	0.18	1	0.5	8.01
1A-3	1	1.02	1	0.13	1	0.88	2	0.94	0	0	1.4	2.05	1.25	0.46	0	0	1	0.67	1.5	0.14	1	0.5	8.73
1A-4	1	1.02	1	0.13	1	0.88	1.75	1.11	0	0	1.4	2.05	1.25	0.46	0	0	1	0.67	1.5	0.14	1	0.5	8.79
1B-1	1.25	1.08	1	0.13	1.2	0.88	1.5	0.94	1	0.83	1	1.99	1.25	0.33	0	0	1	0.61	1.25	0.18	1	0.5	8.51
2A-1	1	0.96	1	0.13	1	1.12	2.5	1.01	0	0	1	2.01	1.25	0.4	0	0	1	0.61	1	0.17	1	0.5	8.52
2A-2	1	0.96	1	0.13	1	1.12	2.25	1.08	0	0	1	2.01	1.25	0.4	0	0	1	0.61	1	0.17	1	0.5	8.42
2A-3	1	0.96	1	0.13	1	1.15	2	0.88	0	0	1.4	2.18	1.25	0.53	0	0	1	0.67	1.25	0.14	1	0.5	9.05
2B-1	1	0.96	1	0.13	1.2	1.15	1	0.73	1.25	0.84	1	1.96	1	0.42	0	0	1	0.60	1.25	0.31	1	0.5	8.11
3A-1	2	1.37	2	0.16	1.3	0.60	2.5	0.98	0	0	1	1.93	1.5	0.34	1	0.19	1	0.64	1.25	0.18	1	0.5	10.28
3A-2	2	1.37	2	0.16	1.3	0.60	2.25	1.25	0	0	1	1.93	1.5	0.34	1	0.19	1	0.64	1.25	0.22	1	0.5	10.70
4A-1	1.75	1.21	1	0.13	1.2	1.35	2.5	1.01	0	0	1	1.83	1	0	0	0	1.5	0.80	0	0.00	1	0.5	9.92
4A-2	1.75	1.21	1	0.13	1.2	1.35	2.25	1.22	0	0	1.1	1.83	1	0.17	0	0	1.3	0.67	0	0.00	1	0.5	10.16
1A-1-Int-Opt 11	1.25	1.08	1	0.13	1.3	0.95	2	0.94	0	0	1	1.99	1.25	0.33	0	0	1	0.61	1.25	0.18	1	0.5	8.33
2A-1-Int-Opt 10	1	0.96	1	0.13	1.4	1.12	2.5	1.01	0	0	1	2.01	1.25	0.4	0	0	1	0.69	1	0.31	1	0.5	9.18
2A-1-Int-Opt 11	1	0.96	1	0.13	1.3	1.12	2.5	1.01	0	0	1	2.01	1.25	0.4	0	0	1	0.69	1	0.17	1	0.5	8.93
2A-1-Wng-Opt 10	1	0.96	1	0.13	1	1.12	2.5	1.01	0	0	1.4	2.18	1.25	0.4	0	0	1	0.69	1	0.17	1	0.5	9.64
2A-1-Wng-Opt 11	1	0.96	1	0.13	1	1.12	2.5	1.01	0	0	1.3	2.18	1.25	0.4	0	0	1	0.69	1	0.17	1	0.5	9.42
2A-1-Wng-Opt 12	1	0.96	1	0.13	1	1.12	2.5	1.01	0	0	1.5	2.74	1.25	0.4	0	0	1	0.69	1	0.17	1	0.5	10.70
2A-1-Tail-Opt 11	1	0.96	1	0.13	1	1.12	2.5	1.01	0	0	1	2.01	1.25	0.4	0	0	1	0.69	1	0.17	1.3	0.59	8.87
2A-1-CS-Opt 11	1	0.96	1	0.13	1	1.12	2.5	1.01	0	0	1.3	2.04	1.25	0.4	0	0	1	0.69	1	0.17	1	0.5	9.24
2A-1-CS-Opt 14	1	0.96	1	0.13	1	1.12	2.5	1.01	0	0	1.5	2.11	1.25	0.4	0	0	1	0.69	1	0.17	1	0.5	9.75
2A-3-Wng-Opt 11	1	0.96	1	0.13	1	1.12	2.5	1.01	0	0	1	2.20	1.25	0.4	0	0	1	0.69	1	0.17	1	0.5	8.79
2B-1-OTF5	1	0.96	1	0.13	1	1.16	2.5	0.72	1.25	0.84	1	1.96	1	0.42	0	0	1	0.60	1	0.31	1	0.5	8.88

SC-1a-2 Certification Development Testing

Option	LO tank	Wght	RP tank	Wght	Inter-tank	Wght	LH2 Tank	Wght	LH2 tank outer shell	Wght	Wing	Wght	Fairings	Wght	Canard	Wght	Thrust struct	Wght	Aft Skirt	Wght	Tail	Wght	Total score
1A-1	1.2	1.08	0	0.13	1	0.85	1	0.94	0	0	1	1.99	1.25	0.33	0	0	1	0.61	0	0.18	1	0.5	6.60
1A -2	1.2	1.08	0	0.13	1	0.85	1	1.11	0	0	1	1.99	1.25	0.33	0	0	1	0.61	0	0.18	1	0.5	6.77
1A-3	1	1.02	0	0.13	1	0.88	1	0.94	0	0	1.2	2.05	1.25	0.46	0	0	1	0.67	0	0.14	1	0.5	7.05
1A-4	1	1.02	0	0.13	1	0.88	1	1.11	0	0	1.2	2.05	1.25	0.46	0	0	1	0.67	0	0.14	1	0.5	7.22
1B-1	1.2	1.08	0	0.13	1	0.88	2	0.94	2	0.83	1	1.99	1.25	0.33	0	0	1	0.61	0	0.18	1	0.5	9.23
2A-1	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	1	2.01	1.25	0.4	0	0	1	0.61	0	0.17	1	0.5	8.22
2A-2	1	0.96	0	0.13	1	1.12	2.5	1.08	0	0	1	2.01	1.25	0.4	0	0	1	0.61	0	0.17	1	0.5	8.40
2A-3	1	0.96	0	0.13	1	1.15	1	0.88	0	0	1.2	2.18	1.25	0.53	0	0	1	0.67	0	0.14	1	0.5	7.44
2B-1	1	0.96	0	0.13	1.1	1.15	2	0.73	2	0.84	1	1.96	1	0.42	0	0	1	0.60	0	0.31	1	0.5	8.85
3A-1	5	1.37	0	0.16	1.2	0.60	5	0.98	0	0	1	1.93	1.5	0.34	1	0.19	1	0.64	0	0.18	1	0.5	16.24
3A-2	5	1.37	0	0.16	1.2	0.60	5	1.25	0	0	1	1.93	1.5	0.34	1	0.19	1	0.64	0	0.22	1	0.5	17.59
4A-1	5	1.21	0	0.13	1.1	1.35	5	1.01	0	0	1	1.83	1	0	0	0	2	0.80	0	0.00	1	0.5	16.52
4A-2	5	1.21	0	0.13	1.2	1.35	5	1.22	0	0	1.1	1.83	1	0.17	0	0	1.2	0.67	0	0.00	1	0.5	17.26
1A-1-Int-Opt 11	1.2	1.08	0	0.13	2	0.95	1	0.94	0	0	1	1.99	1.25	0.33	0	0	1	0.61	0	0.18	1	0.5	7.65
2A-1-Int-Opt 10	1	0.96	0	0.13	2	1.12	2.5	1.01	0	0	1	2.01	1.25	0.4	0	0	1	0.69	0	0.31	1	0.5	9.42
2A-1-Int-Opt 11	1	0.96	0	0.13	2	1.12	2.5	1.01	0	0	1	2.01	1.25	0.4	0	0	1	0.69	0	0.17	1	0.5	9.42
2A-1-Wng-Opt 10	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	2	2.18	1.25	0.4	0	0	1	0.69	0	0.17	1	0.5	10.65
2A-1-Wng-Opt 11	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	2	2.18	1.25	0.4	0	0	1	0.69	0	0.17	1	0.5	10.65
2A-1-Wng-Opt 12	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	2	2.74	1.25	0.4	0	0	1	0.69	0	0.17	1	0.5	11.77
2A-1-Tail-Opt 11	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	1	2.01	1.25	0.4	0	0	1	0.69	0	0.17	2	0.59	8.98
2A-1-CS-Opt 11	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	1	2.04	1.25	0.4	0	0	1	0.69	0	0.17	1	0.5	8.33
2A-1-CS-Opt 14	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	1	2.11	1.25	0.4	0	0	1	0.69	0	0.17	1	0.5	8.40
2A-3-Wng-Opt 11	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	2	2.20	1.25	0.4	0	0	1	0.69	0	0.17	1	0.5	10.69
2B-1-OTF5	1	0.96	0	0.13	1	1.16	2	0.72	2	0.84	1	1.96	1	0.42	0	0	1	0.60	0	0.31	1	0.5	8.72

SC-1a-3 Certification Demonstration testing

Option	LO tank	Wght	RP tank	Wght	Inter-tank	Wght	LH2 Tank	Wght	LH2 tank outer shell	Wght	Wing	Wght	Fairings	Wght	Canard	Wght	Thrust struct	Wght	Aft Skirt	Wght	Tail	Wght	Total score
1A-1	1.24	1.08	1	0.13	1	0.85	1.7	0.94	0	0	1	1.99	1	0.33	0	0	1.2	0.61	1	0.18	1	0.5	7.65
1A -2	1.24	1.08	1	0.13	1	0.85	1.7	1.11	0	0	1	1.99	1	0.33	0	0	1.2	0.61	1	0.18	1	0.5	7.94
1A-3	1	1.02	1	0.13	1	0.88	1.7	0.94	0	0	1.2	2.05	1	0.46	0	0	1.2	0.67	1	0.14	1	0.5	7.99
1A-4	1	1.02	1	0.13	1	0.88	1.7	1.11	0	0	1.2	2.05	1	0.46	0	0	1.2	0.67	1	0.14	1	0.5	8.28
1B-1	1.24	1.08	1	0.13	1	0.88	1	0.94	1	0.83	1	1.99	1	0.33	0	0	1.2	0.61	1	0.18	1	0.5	7.85
2A-1	1	0.96	1	0.13	1	1.12	2.25	1.01	0	0	1	2.01	1	0.4	0	0	1.2	0.61	1	0.17	1	0.5	8.29
2A-2	1	0.96	1	0.13	1	1.12	2.25	1.08	0	0	1	2.01	1	0.4	0	0	1.2	0.61	1	0.17	1	0.5	8.45
2A-3	1	0.96	1	0.13	1	1.15	2.25	0.88	0	0	1.3	2.18	1	0.53	0	0	1.2	0.67	1	0.14	1	0.5	9.02
2B-1	1	0.96	1	0.13	1	1.15	1	0.73	1.3	0.84	1	1.96	1	0.42	0	0	1.2	0.60	1	0.31	1	0.5	7.97
3A-1	1.41	1.37	1.5	0.16	1.5	0.60	1.7	0.98	0	0	1	1.93	1	0.34	1	0.19	1.2	0.64	1	0.18	1	0.5	8.64
3A-2	1.41	1.37	1.5	0.16	1.5	0.60	1.7	1.25	0	0	1	1.93	1	0.34	1	0.19	1.2	0.64	1	0.22	1	0.5	9.14
4A-1	1.16	1.21	1	0.13	2	1.35	1.7	1.01	0	0	1	1.83	1	0	0	0	1	0.80	0	0.00	1	0.5	9.08
4A-2	1.16	1.21	1	0.13	2	1.35	1.7	1.22	0	0	1.1	1.83	1	0.17	0	0	1.2	0.67	0	0.00	1	0.5	9.79
1A-1-Int-Opt 11	1.24	1.08	1	0.13	1	0.95	1.7	0.94	0	0	1	1.99	1	0.33	0	0	1.2	0.61	1	0.18	1	0.5	7.75
2A-1-Int-Opt 10	1	0.96	1	0.13	1	1.12	2.25	1.01	0	0	1	2.01	1	0.4	0	0	1.2	0.69	1	0.31	1	0.5	8.52
2A-1-Int-Opt 11	1	0.96	1	0.13	1	1.12	2.25	1.01	0	0	1	2.01	1	0.4	0	0	1.2	0.69	1	0.17	1	0.5	8.38
2A-1-Wng-Opt 10	1	0.96	1	0.13	1	1.12	2.25	1.01	0	0	1.3	2.18	1	0.4	0	0	1.2	0.69	1	0.17	1	0.5	9.21
2A-1-Wng-Opt 11	1	0.96	1	0.13	1	1.12	2.25	1.01	0	0	1.2	2.18	1	0.4	0	0	1.2	0.69	1	0.17	1	0.5	8.99
2A-1-Wng-Opt 12	1	0.96	1	0.13	1	1.12	2.25	1.01	0	0	1.5	2.74	1	0.4	0	0	1.2	0.69	1	0.17	1	0.5	10.48
2A-1-Tail-Opt 11	1	0.96	1	0.13	1	1.12	2.25	1.01	0	0	1	2.01	1	0.4	0	0	1.2	0.69	1	0.17	1	0.59	8.47
2A-1-CS-Opt 11	1	0.96	1	0.13	1	1.12	2.25	1.01	0	0	1	2.04	1	0.4	0	0	1.2	0.69	1	0.17	1	0.5	8.41
2A-1-CS-Opt 14	1	0.96	1	0.13	1	1.12	2.25	1.01	0	0	1	2.11	1	0.4	0	0	1.2	0.69	1	0.17	1	0.5	8.48
2A-3-Wng-Opt 11	1	0.96	1	0.13	1	1.12	2.25	1.01	0	0	1	2.20	1	0.4	0	0	1.2	0.69	1	0.17	1	0.5	8.57
2B-1-OTF5	1	0.96	1	0.13	1	1.16	1	0.72	1.3	0.84	1	1.96	1	0.42	0	0	1.2	0.60	1	0.31	1	0.5	7.97

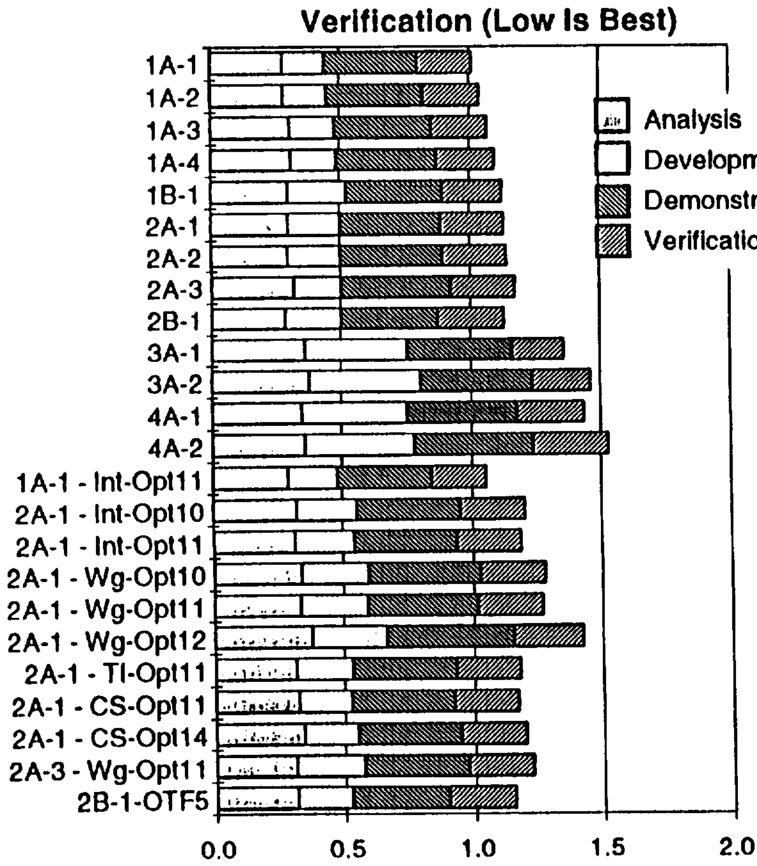
SC-1a Certification Ranking

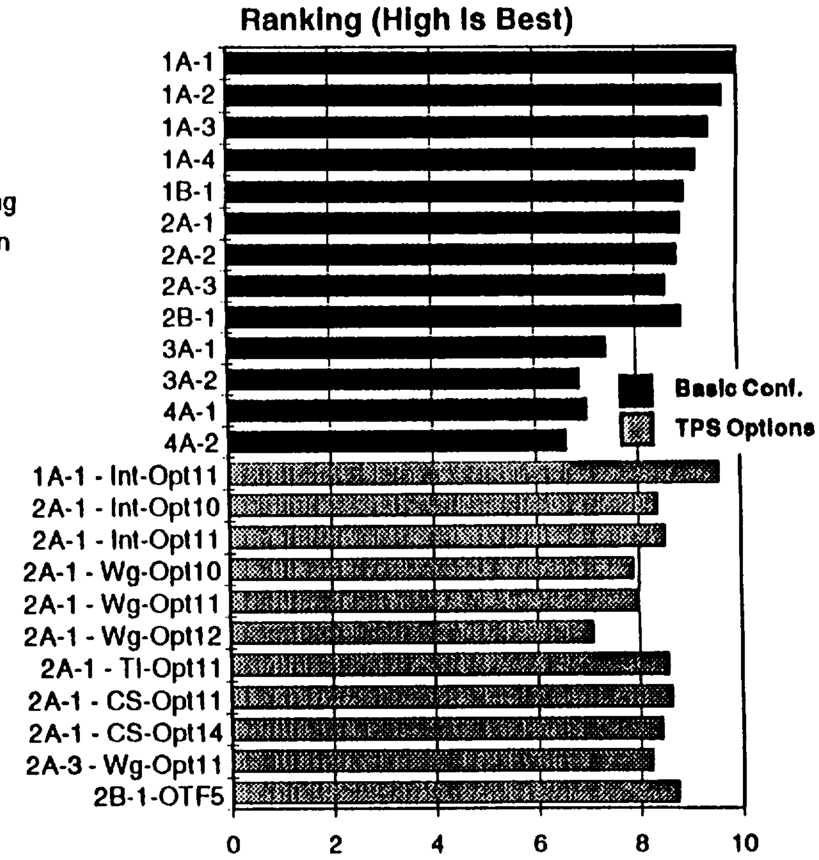
Option	1a 1 Total	Wght	1a 2 Total	Wght	1a 3 Total	Wght	Grand total
1A-1	1.00	0.35	1.00	0.20	1.00	0.45	1.00
1A -2	1.01	0.35	1.03	0.20	1.04	0.45	1.02
1A-3	1.10	0.35	1.07	0.20	1.04	0.45	1.07
1A-4	1.11	0.35	1.09	0.20	1.08	0.45	1.09
1B-1	1.07	0.35	1.40	0.20	1.03	0.45	1.12
2A-1	1.07	0.35	1.25	0.20	1.08	0.45	1.11
2A-2	1.06	0.35	1.27	0.20	1.10	0.45	1.12
2A-3	1.14	0.35	1.13	0.20	1.18	0.45	1.16
2B-1	1.02	0.35	1.34	0.20	1.04	0.45	1.09
3A-1	1.29	0.35	2.46	0.20	1.13	0.45	1.45
3A-2	1.35	0.35	2.67	0.20	1.20	0.45	1.54
4A-1	1.25	0.35	2.50	0.20	1.19	0.45	1.47
4A-2	1.28	0.35	2.62	0.20	1.28	0.45	1.55
1A-1-Int-Opt 11	1.05	0.35	1.16	0.20	1.01	0.45	1.05
2A-1-Int-Opt 10	1.16	0.35	1.43	0.20	1.11	0.45	1.19
2A-1-Int-Opt 11	1.12	0.35	1.43	0.20	1.10	0.45	1.17
2A-1-Wng-Opt 10	1.21	0.35	1.61	0.20	1.20	0.45	1.29
2A-1-Wng-Opt 11	1.19	0.35	1.61	0.20	1.18	0.45	1.27
2A-1-Wng-Opt 12	1.35	0.35	1.78	0.20	1.37	0.45	1.45
2A-1-Tail-Opt 11	1.12	0.35	1.36	0.20	1.11	0.45	1.16
2A-1-CS-Opt 11	1.16	0.35	1.26	0.20	1.10	0.45	1.15
2A-1-CS-Opt 14	1.23	0.35	1.27	0.20	1.11	0.45	1.18
2A-3-Wng-Opt 11	1.11	0.35	1.62	0.20	1.12	0.45	1.22
2B-1-OTF5	1.12	0.35	1.32	0.20	1.04	0.45	1.12

1A Option Ranked Best For Verification Effort

SSTO

*1b. **Verification Effort - (Qualitative evaluation) - The candidate vehicle options are rated according to the perceived effort of analysis, development testing, demonstration testing, and inspection required for verification of structure and TPS. Verification includes certification plus the addition of inspection to ascertain adherence of the as-built vehicle to drawings and specifications.***





NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

SC-1b-1 Verification Inspection

Option	LO tank	Wght	RP tank	Wght	Inter-tank	Wght	LH2 Tank	Wght	LH2 tank outer shell	Wght	Wing	Wght	Fairings	Wght	Canard	Wght	Thrust struct	Wght	Aft Skirt	Wght	Tail	Wght	Total score
1A-1	1.00	1.08	1	0.13	1	0.85	2	0.94	0	0	1	1.99	1	0.33	0	0	1.5	0.61	1	0.18	1	0.5	7.85
1A -2	1.00	1.08	1	0.13	1	0.85	2	1.11	0	0	1	1.99	1	0.33	0	0	1.5	0.61	1	0.18	1	0.5	8.19
1A-3	1.00	1.02	1	0.13	1	0.88	2	0.94	0	0	1	2.05	1	0.46	0	0	1.5	0.67	1	0.14	1	0.5	8.06
1A-4	1.00	1.02	1	0.13	1	0.88	2	1.11	0	0	1	2.05	1	0.46	0	0	1.5	0.67	1	0.14	1	0.5	8.40
1B-1	1.00	1.08	1	0.13	1	0.88	1.5	0.94	1.5	0.83	1	1.99	1	0.33	0	0	1.5	0.61	1	0.18	1	0.5	8.66
2A-1	2.00	0.96	1	0.13	1	1.12	2	1.01	0	0	1	2.01	1	0.4	0	0	1.5	0.61	1	0.17	1	0.5	9.18
2A-2	2.00	0.96	1	0.13	1	1.12	2	1.08	0	0	1	2.01	1	0.4	0	0	1.5	0.61	1	0.17	1	0.5	9.32
2A-3	2.00	0.96	1	0.13	1	1.15	2	0.88	0	0	1	2.18	1	0.53	0	0	1.5	0.67	1	0.14	1	0.5	9.31
2B-1	2.00	0.96	1	0.13	1	1.15	1.5	0.73	1.5	0.84	1	1.96	1	0.42	0	0	1.5	0.60	1	0.31	1	0.5	9.64
3A-1	1.00	1.37	2	0.16	1.2	0.60	1	0.98	0	0	1	1.93	1	0.34	1	0.19	1.5	0.64	1	0.18	1	0.5	7.49
3A-2	1.00	1.37	2	0.16	1.2	0.60	1.5	1.25	0	0	1	1.93	1	0.34	1	0.19	1.5	0.64	1	0.22	1	0.5	8.43
4A-1	3.00	1.21	1	0.13	1.3	1.35	1	1.01	0	0	1	1.83	1	0	0	0	1	0.80	0	0.00	1	0.5	9.65
4A-2	3.00	1.21	1	0.13	1.3	1.35	1.5	1.22	0	0	1	1.83	1	0.17	0	0	1.5	0.67	0	0.00	1	0.5	10.85
1A-1-Int-Opt 11	1.00	1.08	1	0.13	1	0.95	2	0.94	0	0	1	1.99	1	0.33	0	0	1.5	0.61	1	0.18	1	0.5	7.95
2A-1-Int-Opt 10	2.00	0.96	1	0.13	1	1.12	2	1.01	0	0	1	2.01	1	0.4	0	0	1.5	0.69	1	0.31	1	0.5	9.43
2A-1-Int-Opt 11	2.00	0.96	1	0.13	1	1.12	2	1.01	0	0	1	2.01	1	0.4	0	0	1.5	0.69	1	0.17	1	0.5	9.30
2A-1-Wng-Opt 10	2.00	0.96	1	0.13	1	1.12	2	1.01	0	0	1	2.18	1	0.4	0	0	1.5	0.69	1	0.17	1	0.5	9.47
2A-1-Wng-Opt 11	2.00	0.96	1	0.13	1	1.12	2	1.01	0	0	1	2.18	1	0.4	0	0	1.5	0.69	1	0.17	1	0.5	9.47
2A-1-Wng-Opt 12	2.00	0.96	1	0.13	1	1.12	2	1.01	0	0	1	2.74	1	0.4	0	0	1.5	0.69	1	0.17	1	0.5	10.03
2A-1-Tail-Opt 11	2.00	0.96	1	0.13	1	1.12	2	1.01	0	0	1	2.01	1	0.4	0	0	1.5	0.69	1	0.17	1	0.59	9.39
2A-1-CS-Opt 11	2.00	0.96	1	0.13	1	1.12	2	1.01	0	0	1	2.04	1	0.4	0	0	1.5	0.69	1	0.17	1	0.5	9.33
2A-1-CS-Opt 14	2.00	0.96	1	0.13	1	1.12	2	1.01	0	0	1	2.11	1	0.4	0	0	1.5	0.69	1	0.17	1	0.5	9.40
2A-3-Wng-Opt 11	2.00	0.96	1	0.13	1	1.12	2	1.01	0	0	1	2.20	1	0.4	0	0	1.5	0.69	1	0.17	1	0.5	9.49
2B-1-OTF5	2.00	0.96	1	0.13	1	1.16	1.5	0.72	1.5	0.84	1	1.96	1	0.42	0	0	1.5	0.60	1	0.31	1	0.5	9.63

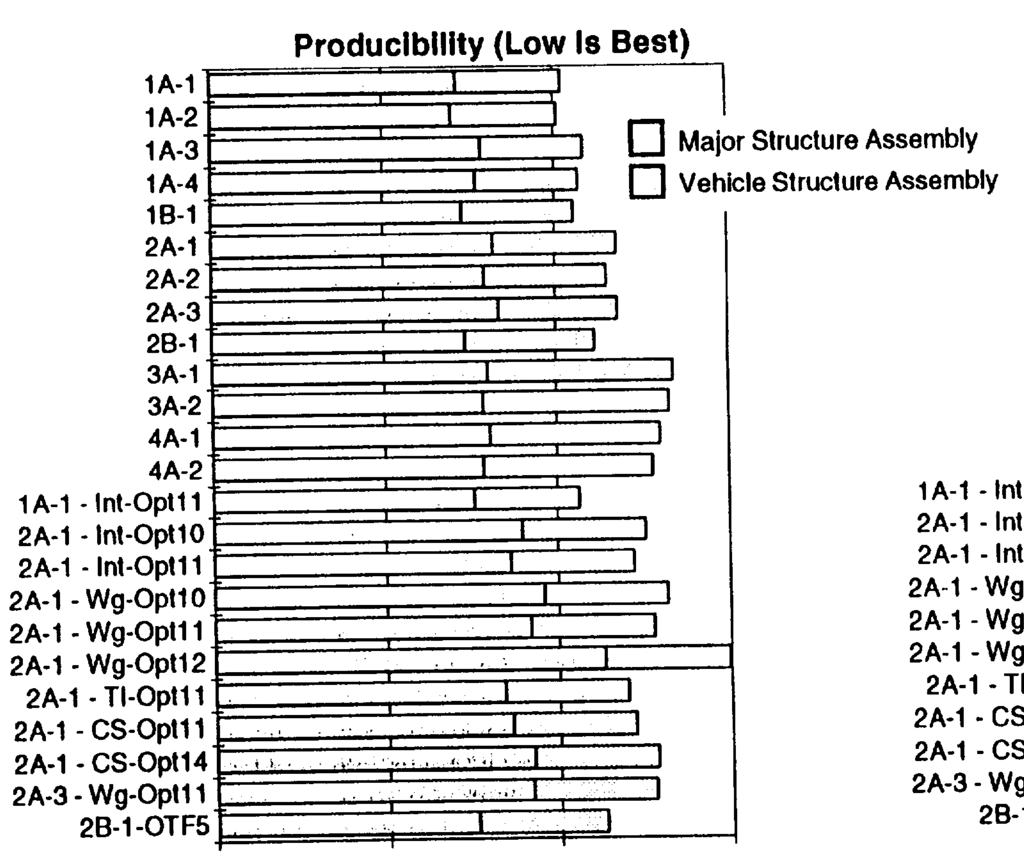
SC-1b Verification Ranking

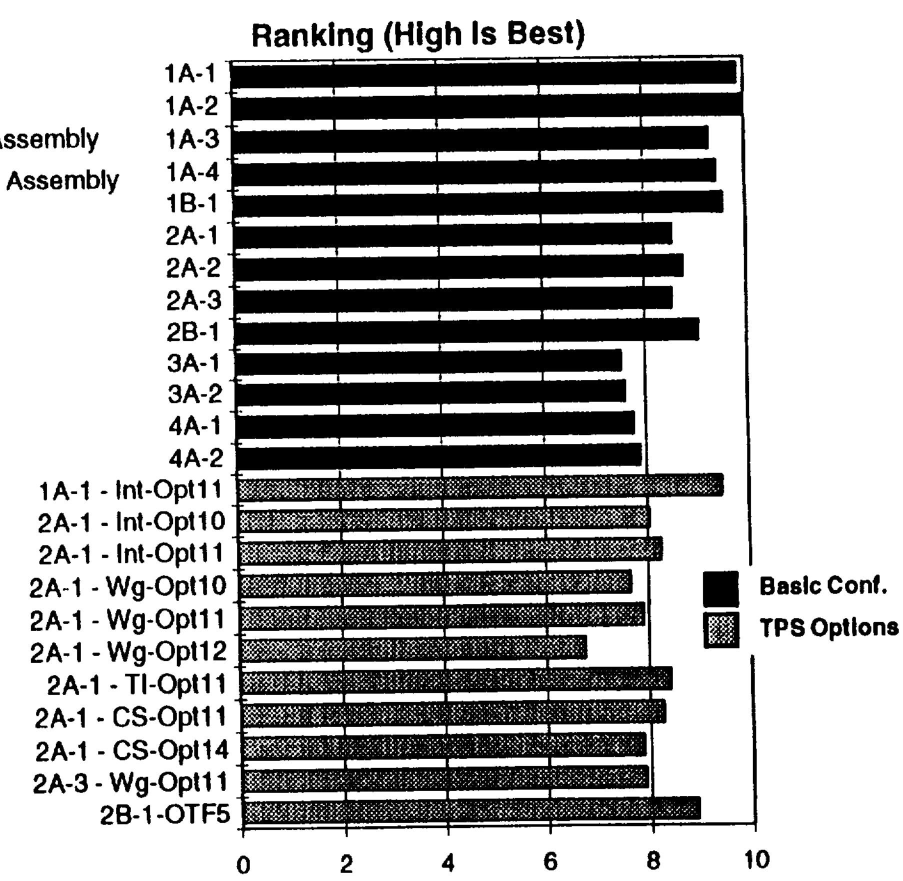
Option	1a 1 Total	Wght	1a 2 Total	Wght	1a 3 Total	Wght	1b1 Inspection	Wght	Grand total
1A-1	1.00	0.28	1.00	0.16	1.00	0.36	1.05	0.20	1.01
1A -2	1.01	0.28	1.03	0.16	1.04	0.36	1.09	0.20	1.04
1A-3	1.10	0.28	1.07	0.16	1.04	0.36	1.08	0.20	1.07
1A-4	1.11	0.28	1.09	0.16	1.08	0.36	1.12	0.20	1.10
1B-1	1.07	0.28	1.40	0.16	1.03	0.36	1.16	0.20	1.12
2A-1	1.07	0.28	1.25	0.16	1.08	0.36	1.23	0.20	1.14
2A-2	1.06	0.28	1.27	0.16	1.10	0.36	1.24	0.20	1.15
2A-3	1.14	0.28	1.13	0.16	1.18	0.36	1.24	0.20	1.17
2B-1	1.02	0.28	1.34	0.16	1.04	0.36	1.29	0.20	1.13
3A-1	1.29	0.28	2.46	0.16	1.13	0.36	1.00	0.20	1.36
3A-2	1.35	0.28	2.67	0.16	1.20	0.36	1.13	0.20	1.46
4A-1	1.25	0.28	2.50	0.16	1.19	0.36	1.29	0.20	1.44
4A-2	1.28	0.28	2.62	0.16	1.28	0.36	1.45	0.20	1.53
1A-1-Int-Opt 11	1.05	0.28	1.16	0.16	1.01	0.36	1.06	0.20	1.06
2A-1-Int-Opt 10	1.16	0.28	1.43	0.16	1.11	0.36	1.26	0.20	1.21
2A-1-Int-Opt 11	1.12	0.28	1.43	0.16	1.10	0.36	1.24	0.20	1.19
2A-1-Wng-Opt 10	1.21	0.28	1.61	0.16	1.20	0.36	1.26	0.20	1.28
2A-1-Wng-Opt 11	1.19	0.28	1.61	0.16	1.18	0.36	1.26	0.20	1.27
2A-1-Wng-Opt 12	1.35	0.28	1.78	0.16	1.37	0.36	1.34	0.20	1.42
2A-1-Tail-Opt 11	1.12	0.28	1.36	0.16	1.11	0.36	1.25	0.20	1.18
2A-1-CS-Opt 11	1.16	0.28	1.26	0.16	1.10	0.36	1.25	0.20	1.17
2A-1-CS-Opt 14	1.23	0.28	1.27	0.16	1.11	0.36	1.26	0.20	1.20
2A-3-Wng-Opt 11	1.11	0.28	1.62	0.16	1.12	0.36	1.27	0.20	1.23
2B-1-OTF5	1.12	0.28	1.32	0.16	1.04	0.36	1.29	0.20	1.16

1A-1 And 1A-2 Ranked Best For Producibility Effort

SSTO

1c. Producibility Effort - (Qualitative evaluation) - The candidate vehicle options are rated according to the perceived effort of producibility (tooling and fabrication).





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SC-1c-1 Producibility - Major Structure Assemblies

Option	LO tank	Wght	RP tank	Wght	Inter-tank	Wght	LH2 Tank	Wght	LH2 tank outer shell	Wght	Wing	Wght	Fairings	Wght	Canard	Wght	Thrust struct	Wght	Aft Skirt	Wght	Tail	Wght	Total score
1A-1	1	1.08	1	0.13	1	0.85	2.5	0.94	0	0	1	1.99	1	0.33	0	0	1	0.61	1	0.18	1	0.5	8.02
1A -2	1	1.08	1	0.13	1	0.85	2	1.11	0	0	1	1.99	1	0.33	0	0	1	0.61	1	0.18	1	0.5	7.89
1A-3	1	1.02	1	0.13	1	0.88	2.5	0.94	0	0	1.3	2.05	1	0.46	0	0	1	0.67	1	0.14	1	0.5	8.81
1A-4	1	1.02	1	0.13	1	0.88	2	1.11	0	0	1.3	2.05	1	0.46	0	0	1	0.67	1	0.14	1	0.5	8.68
1B-1	1	1.08	1	0.13	1	0.88	1.5	0.94	1.3	0.83	1	1.99	1	0.33	0	0	1	0.61	1	0.18	1	0.5	8.19
2A-1	1.3	0.96	1	0.13	1	1.12	3	1.01	0	0	1	2.01	1	0.4	0	0	1	0.61	1	0.17	1	0.5	9.21
2A-2	1.3	0.96	1	0.13	1	1.12	2.5	1.08	0	0	1	2.01	1	0.4	0	0	1	0.61	1	0.17	1	0.5	8.88
2A-3	1.3	0.96	1	0.13	1	1.15	2.5	0.88	0	0	1.3	2.18	1	0.53	0	0	1	0.67	1	0.14	1	0.5	9.40
2B-1	1.3	0.96	1	0.13	1	1.15	1.5	0.73	1	0.84	1	1.96	1	0.42	0	0	1	0.60	1	0.31	1	0.5	8.25
3A-1	2	1.37	2	0.16	1.2	0.60	1.5	0.98	0	0	1	1.93	1	0.34	1	0.19	1	0.64	1	0.18	1	0.5	9.03
3A-2	2	1.37	2	0.16	1.2	0.60	1	1.25	0	0	1	1.93	1	0.34	1	0.19	1	0.64	1	0.22	1	0.5	8.85
4A-1	2	1.21	1	0.13	1.2	1.35	1.5	1.01	0	0	1	1.83	0	0	0	0	1.3	0.80	0	0.00	1	0.5	9.05
4A-2	2	1.21	1	0.13	1.3	1.35	1	1.22	0	0	1.1	1.83	0.5	0.17	0	0	1.1	0.67	0	0.00	1	0.5	8.86
1A-1-Int-Opt 11	1	1.08	1	0.13	1.4	0.95	2.5	0.94	0	0	1	1.99	1	0.33	0	0	1	0.61	1	0.18	1	0.5	8.50
2A-1-Int-Opt 10	1.3	0.96	1	0.13	1.6	1.12	3	1.01	0	0	1	2.01	1	0.4	0	0	1	0.69	1	0.31	1	0.5	10.10
2A-1-Int-Opt 11	1.3	0.96	1	0.13	1.4	1.12	3	1.01	0	0	1	2.01	1	0.4	0	0	1	0.69	1	0.17	1	0.5	9.74
2A-1-Wng-Opt 10	1.3	0.96	1	0.13	1	1.12	3	1.01	0	0	1.6	2.18	1	0.4	0	0	1	0.69	1	0.17	1	0.5	10.77
2A-1-Wng-Opt 11	1.3	0.96	1	0.13	1	1.12	3	1.01	0	0	1.4	2.18	1	0.4	0	0	1	0.69	1	0.17	1	0.5	10.33
2A-1-Wng-Opt 12	1.3	0.96	1	0.13	1	1.12	3	1.01	0	0	2	2.74	1	0.4	0	0	1	0.69	1	0.17	1	0.5	12.76
2A-1-Tail-Opt 11	1.3	0.96	1	0.13	1	1.12	3	1.01	0	0	1	2.01	1	0.4	0	0	1	0.69	1	0.17	1.2	0.59	9.50
2A-1-CS-Opt 11	1.3	0.96	1	0.13	1	1.12	3	1.01	0	0	1.2	2.04	1	0.4	0	0	1	0.69	1	0.17	1	0.5	9.73
2A-1-CS-Opt 14	1.3	0.96	1	0.13	1	1.12	3	1.01	0	0	1.5	2.11	1	0.4	0	0	1	0.69	1	0.17	1	0.5	10.45
2A-3-Wng-Opt 11	1.3	0.96	1	0.13	1	1.12	3	1.01	0	0	1.4	2.20	1	0.4	0	0	1	0.69	1	0.17	1	0.5	10.36
2B-1-OTF5	1.3	0.96	1	0.13	1	1.16	1.5	0.72	1.3	0.84	1	1.96	1	0.42	0	0	1	0.60	1	0.31	1	0.5	8.49

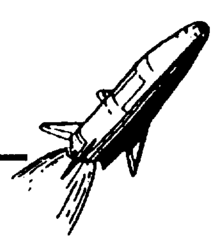
SC-1c-2 Producibility - Vehicle structure assembly

Option	Total score
1A-1	1.03
1A -2	1.03
1A-3	1
1A-4	1
1B-1	1.09
2A-1	1.20
2A-2	1.20
2A-3	1.16
2B-1	1.26
3A-1	1.81
3A-2	1.81
4A-1	1.65
4A-2	1.65
1A-1-Int-Opt 11	1.03
2A-1-Int-Opt 10	1.20
2A-1-Int-Opt 11	1.20
2A-1-Wng-Opt 10	1.20
2A-1-Wng-Opt 11	1.20
2A-1-Wng-Opt 12	1.20
2A-1-Tail-Opt 11	1.20
2A-1-CS-Opt 11	1.20
2A-1-CS-Opt 14	1.20
2A-3-Wng-Opt 11	1.20
2B-1-OTF5	1.26

SC-1c Producibility Ranking

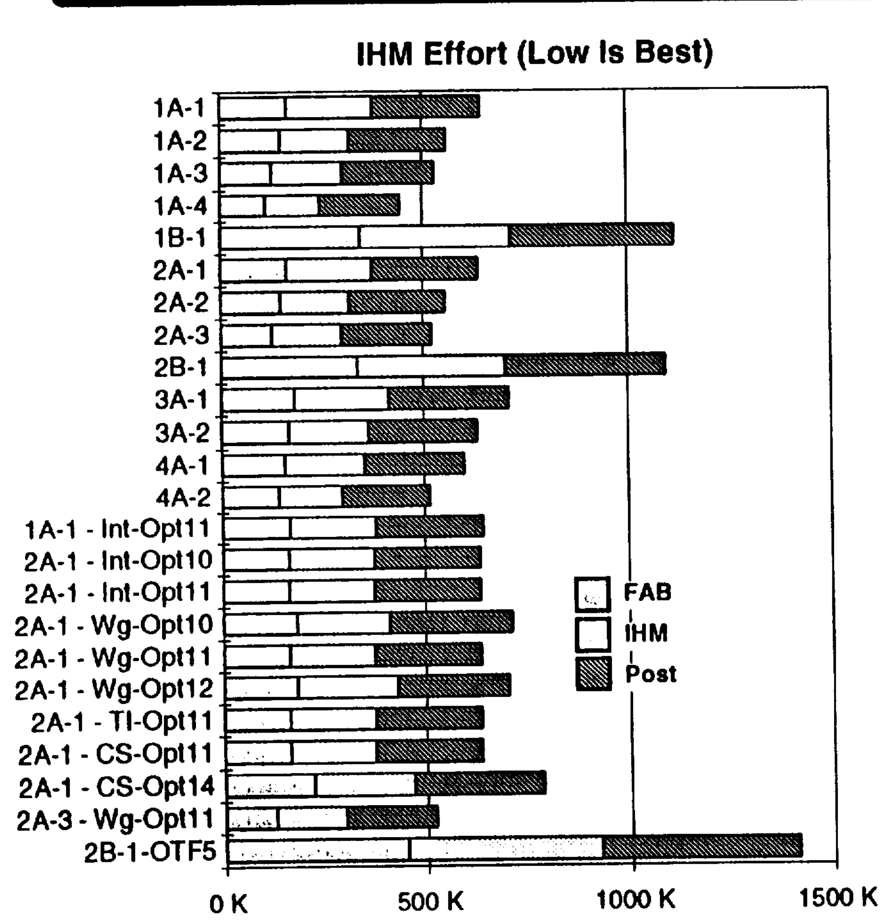
Option	1c 1 Total	Wght	1c 2 Total	Wght	Grand total score
1A-1	1.02	0.70	1.03	0.30	1.02
1A -2	1.00	0.70	1.03	0.30	1.01
1A-3	1.12	0.70	1.00	0.30	1.08
1A-4	1.10	0.70	1.00	0.30	1.07
1B-1	1.04	0.70	1.09	0.30	1.05
2A-1	1.17	0.70	1.20	0.30	1.18
2A-2	1.13	0.70	1.20	0.30	1.15
2A-3	1.19	0.70	1.16	0.30	1.18
2B-1	1.05	0.70	1.26	0.30	1.11
3A-1	1.14	0.70	1.81	0.30	1.34
3A-2	1.12	0.70	1.81	0.30	1.33
4A-1	1.15	0.70	1.65	0.30	1.30
4A-2	1.12	0.70	1.65	0.30	1.28
1A-1-Int-Opt 10	1.08	0.70	1.03	0.30	1.06
2A-1-Int-Opt 10	1.28	0.70	1.20	0.30	1.26
2A-1-Int-Opt 11	1.23	0.70	1.20	0.30	1.22
2A-1-Wng-Opt 10	1.37	0.70	1.20	0.30	1.32
2A-1-Wng-Opt 11	1.31	0.70	1.20	0.30	1.28
2A-1-Wng-Opt 12	1.62	0.70	1.20	0.30	1.49
2A-1-Tail-Opt 11	1.20	0.70	1.20	0.30	1.20
2A-1-CS-Opt 11	1.23	0.70	1.20	0.30	1.22
2A-1-CS-Opt 14	1.32	0.70	1.20	0.30	1.29
2A-3-Wng-Opt 11	1.31	0.70	1.20	0.30	1.28
2B-1-OTF5	1.08	0.70	1.26	0.30	1.13

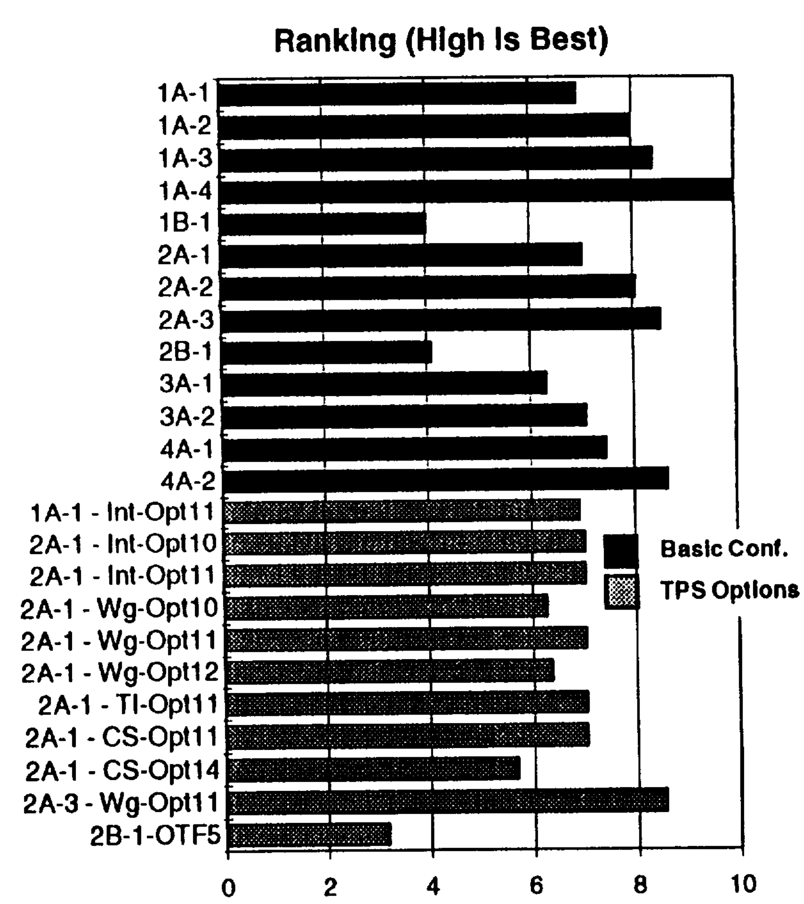
1A-4 Ranked Best For IHM Effort



SSTO

1d. IHM Effort - (Qualitative evaluation) - The candidate vehicle options are rated according to the perceived effort of development and installation of IHM.





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DESIGN AND PRODUCTION COMPLEXITY - IHM Effort

The candidate vehicle options are rated according to the perceived effort of development and installation of IHM.. For example, stringer skin constructions have a limited number of components (skin and TPS layers). However, the complexity of the design will cause more intensive instrumentation to monitor, more intensive inspections and more intensive maintenance. This category is assessed on the surface are that these structures (tanks) will cover. The rationale being that the more surface area the structure has of a particularly difficult design the more difficult the structure will be to inspect, monitor and maintain. The critical features of these designs were considered to be stringer/skin designs, non-integrated designs and material selections.

In general, the design and production complexity - IHM effort was based on several assumptions. These assumptions reflect the difficulties of inspection and instrumentation of the design configurations during the fabrication process, in-flight monitoring and post-flight testing as applied to design and materials selections. This assessment of the different design configurations of SSTO is based on several general assumptions. These assumptions reflect the difficulties of inspection and instrumentation of the design configurations during the three phases of the vehicles life: 1) Fabrication, 2) Post-flight testing and 3) IHM instrumentation as applied to design and materials selections.

Design Assumptions

Several design considerations affect the ability of the structure to be inspected. Primary design considerations include the complexity of the design, the surface area to be inspected, the number of fracture critical components and the number of components to be inspected of instrumented.

Complexity of design

Inherently, simple designs tend to be better suited to inspection and instrumentation than do complex designs. The more complex designs, such as skin and stringer designs have a bend and protrusions that limit accessibility to hardware, inspection techniques, implementation and interpretation. It was also assumed that a more complex design may also require fabrication of specific tooling to facilitate inspection.

Surface Area

Since the NDI technologies to be employed by IHM/NDI are dependent on the area of coverage (rather than on the thickness of the hardware), larger surface areas would be more difficult to inspect and instrument. This implies that the elongated and multiple tank

designs are more difficult to inspect and instrument. This also implies that since the non integrated design configurations have an internal and external structure the area of surface coverage had effectively doubled.

Number of fracture critical components

The level of inspection will not be consistent over the entire vehicle. Fracture critical items (i.e., tank splices, stringers and fittings) will require more intensive inspections and instrumentation than less critical components. Therefore, design configurations that have the largest number of fracture critical components will require the largest number of inspections and instrumentations.

Number of components inspected

Non integrated design configurations have a larger surface area, are more complex and have more critical components. These problems directly affect the NDI/IHM programs by increasing the number of inspection points and area to be inspected.

Materials Assumptions

Due to a lack of information on the composite/TPS structures, it was assumed that the IM7/977-2, AFR 700, Gr/BMI, TMC composite materials and Al-Li alloys have approximately same adaptability to NDI/IHM techniques. In general, the TPS materials assumed that the flexible blanket insulation is considered non inspectable by means other than visual inspection and the C/SiC is more readily adaptable to NDI/IHM.

Critical feature factors

The critical feature factor is the assesment of the complexity of the structure as compared to the most basic design, the sandwich structure.

Critical feature factor of stringer designs

The critical feature factor of stringer design evaluation as applied to the fabrication processes indicated that due to the tight bend radius would be difficult to evaluate using NDI techniques. Current laser based ultrasonics only allow for 30 degree angle from the inspection plane. This configuration has a greater number of critical points of interest. The bond lines and corners are stress concentration points that would require a concentrated level of inspection. A correction factor of 2.0 was applied to the stringer designs to compensate for these difficulties.

The critical feature factor of stringer design evaluation as applied to in-flight IHM monitoring indicated that This configuration has a greater number of critical points of instrumentation. The bond lines and corners associated with the stringer stiffeners are stress concentration points that would require a concentrated level of instrumentation. It is considered that the acoustic emission transducers would be concentrated along the stringers and that the configuration complexity would make the signals more difficult to interpret. A correction factor of 3.0 was applied to the stringer designs to compensate for these difficulties

The critical feature factor of stringer design evaluation as applied to post-flight inspections indicated that due to the tight bend radius would be difficult to evaluate using NDI techniques. Current laser based ultrasonics only allow for 30 degree angle from the inspection plane. This indicates that complex tooling would be required for inspection. This configuration has a greater number of critical points of interest. The bond lines and corners are stress concentration points that would require a concentrated level of inspection. A correction factor of 3.75 was applied to the stringer designs to compensate for these difficulties.

Critical feature factor of non integral designs

The critical feature factor of non integral design evaluation as applied to the fabrication processes indicated that these designs have multiple skins that would require multiple inspections prior to installation. This design also increases the number of bond lines. In addition it was considered that a structure would have to support the internal tank that would increase the number of critical inspection points. A correction factor of 2.0 was applied to non integral designs to compensate for these difficulties.

The critical feature factor of non integral design evaluation as applied to in flight IHM monitoring indicated that these designs have multiple skins would effectively double the area for instrumentation. This design also increases the number of bond lines and a support structure for the internal tank that would increase the number of critical instumentation points. A correction factor of 2.0 was applied to non integral designs to compensate for these difficulties.

The critical feature factor of non integral design evaluation as applied to post flight inspections indicated that these designs have multiple skins would effectively double the area for instrumentation. This design also increases the number of bond lines and adds a support structure for the internal tank that would increase the number of critical inspection points. A correction factor of 2.0 was applied to non integral designs to compensate for these difficulties.

Critical feature factor of designs which utilize ceramic composites

The critical feature factor of designs that utilize ceramic composites as applied to fabrication inspections indicated that there has been limited application of NDI techniques applied to ceramic composites. This indicated that inspection of this material may require

advanced techniques or development of techniques. A correction factor of 1.5 was applied to ceramic composite designs to compensate for these difficulties.

The critical feature factor of designs that utilize ceramic composites as applied to in flight IHM monitoring indicated that there has been limited application of NDI techniques applied to ceramic composites. However, since IHM will most likely involve strain measuring devices and acoustic emission, there is no reason to believe that this composite material will interfere with these techniques. A correction factor of 1.0 was applied to composite designs to compensate for these difficulties.

The critical feature factor of designs that utilize ceramic composites as applied to post flight inspections indicated that there has been limited application of NDI techniques applied to ceramic composites. This indicated that inspection of this material may require advanced techniques or developement of techniques. A correction factor of 2.0 was applied to ceramic composite designs to compensate for these difficulties.

Critical feature factor of designs which utilize TABI or AFRSI blankets

The critical feature factor of designs that utilize TABI or AFRSI blankets as applied to fabrication inspections indicated that there has been limited application of NDI techniques applied to TABI or AFRSI blankets. This indicated that inspection of this material may require advanced techniques or development of techniques. It is also expected that if these techniques cannot be developed then the blankets will require a simple visual inspection only. Therefore no correction is necessary (a correction factor of 1.0) for designs with TABI or AFRSI blankets.

The critical feature factor of designs that utilize TABI or AFRSI blankets as applied to in flight IHM monitoring indicated that there has been limited application of NDI techniques applied to TABI or AFRSI blankets. This indicated that inspection of this material may require advanced techniques or development of techniques. It is also expected that if these techniques cannot be developed and the blankets will not be monitored during flight. Therefore no correction is necessary (a correction factor of 1.0) for designs with TABI or AFRSI blankets.

The critical feature factor of designs that utilize TABI or AFRSI blankets as applied to post flight inspections indicated that there has been limited application of NDI techniques applied to TABI or AFRSI blankets. This indicated that inspection of this material may require advanced techniques or development of techniques. It is also expected that if these techniques cannot be developed the blankets will require a complete visual inspection. A correction factor of 1.5 was applied to designs with TABI or AFRSI blankets to compensate for these difficulties.

Critical feature factor of designs which utilize a mechanical TPS attachment

The critical feature factor of designs that utilize a mechanical attachment as applied to fabrication inspections indicated that there would be additional difficulties associated with this design. This indicated that inspection of this material may require advanced techniques or development of techniques to inspect the mechanical attachments and the gaps. Therefore a correction factor of 2.0 for designs with mechanical attachments.

The critical feature factor of designs that utilize a mechanical attachment as applied to fabrication inspections indicated that there would be additional difficulties associated with in flight IHM monitoring. NDI techniques may have to be concentrated to adequately monitor the mechanical attachments. In addition it is suspected that the attachments may not adequately transfer an acoustic signal from the panel to the base. This may require advanced techniques or development of techniques. It is also expected that if these techniques cannot be developed, then the outer panels may not be monitored during flight. Therefore a correction factor of 2.0 for designs with mechanical attachments was applied.

The critical feature factor of designs that utilize mechanical attachments as applied to post flight inspections indicated that there may be additional difficulties associated with post flight inspections. This indicated that inspection of this material may require advanced techniques, development of techniques and concentrated inspections. A correction factor of 2.0 was applied to designs with mechanical attachments to compensate for these difficulties.

Trade study process

The trade study consisted of a composite score for each of the design configurations for each of the three phases of the vehicles life (in fabrication inspection, post flight inspection and in flight inspection). The composite score for each of these categories is based on composite structure configuration, fracture critical areas, general surface areas as applied to each component of each configuration for fabrication, post flight inspections and in flight monitoring. The score represents the relative difficulty level in inspecting each component. The three parts of the composite score (fabrication, in-flight IHM and post-flight inspection) are weighted equally for the scope of this investigation. The scores are then converted to a 1 to 10 approximation based on 10 being the highest composite score.

The composite scores were based on several assumptions related to the design configurations. The following general and critical areas of inspections were derived from simplified tank structures. It was assumed that the critical areas of inspection only included the area up to the splice, not to the frame. The critical areas were doubled to account for a more intensive inspection or instrumentations. The wing attachment points were scored according to the wing attachment area. Due to the similarities between designs, the wing, nose, canard, payload canister areas are not included in this investigation.

The combined critical feature factor for each structure option was arrived through the following calculation:
No. of skins + No. of TPS layers = Subtotal
Subtotal X Critical Feature Factor = Combined Critical Feature Factor

Table 1. Estimated Surface Areas of Tanks

Configuration	LH2 Tank General	LH2 Tank Critical	LO2 Tank General	LO2 Tank Critical	RP Tank General
1A&B	6940	614	4565	422	1593
2A&B	6509	704	4805	277	1593
3	6591*	430	3250*	362	6190
4	7214*	417	3002*	405	1593

Structure/TPS design analysis

The structures were rated according to its 1) No. of skins, 2) No. of TPS layers and 3) Critical feature factor for each of the three phases of the structures life. The critical feature factor corrects for complicated design features,(stringer and non integrated designs) and material deficiencies (ceramic composites and AFRI or TABI blankets) as applied to the NDE/IHM project. It was generally considered that these variables would increase the difficulty of inspection by an order of magnitude.

Table 2. Number of variables and applied difficulty factor

Trade Option	No. of skins	No. of TPS layers	Sub total	Fabrication Critical features factor	IHM in-flight Critical Feature Factor	Post-flight Critical Feature factor
1	1	2	3	2.0	3.0	3.75
2	2	2	4	1.0	1.0	2.0
5	4	3	7	4.0	4.0	4.0
7	4	3	7	4.0	4.0	4.0
8	1	2	3	2.0	3.0	3.75
9	2	2	4	1.0	1.0	2.0
10	2	2	4	2.0	2.0	2.0
11	2	2	4	1.0	1.0	2.0
12	1	1	2	4.0	6.0	5.0
13	1	1	2	2.0	3.0	3.75
14	1	1	2	8.0	6.0	10.0

Table 3. Critical Feature Factors

Design deficiency	Fabrication	IHM	Post-flight
Sandwich structure	1.0	1.0	1.0
Stringer design	2.0	3.0	3.75
non integral design	2.0	2.0	2.0
ceramic materials*	1.5	1.0	2.0
AFRI or TABI	1.0	1.0	1.5
Mechanical Attack	2.0	2.0	2.0

*Blackglas Option 14

Table 4. Combined Critical Feature Factors

OPTION	Combined Critical Feature Factor for Fabrication	Combined Critical Feature Factor for In-flight IHM	Combined Critical Feature Factor for Post-flight Inspection
1	6	9.0	11.25
2	4	4	8
5	28	28	28
7	28	28	28
8	6	9.0	11.25
9	4	4	8
10	8	8	8
11	4	4	8
12	8	12	10
13	4	6	7.5
14	16	12	20

DESIGN1D.XLS

CONFIG		CRITICAL	LH2	LH2	CRITICAL	LO2	LO2	RP	CRITICAL	WING	WING	TOTALS	**RATING**
		FEATURE	GENERAL	CRITICAL	FEATURE	GENERAL	CRITICAL	GENERAL	FEATURE	GENERAL	ATTACH		
		FACTOR	AREA	AREA	FACTOR	AREA	AREA	AREA	FACTOR	AREA	FACTOR		
			6940	1228		4565	844	1593		4705	4705		
1A-1	FAB	6	41640	7368	6	27390	5064	9558	4	18820	56460	166300	
	IHM	9	62460	11052	9	41085	7596	14337	4	18820	56460	211810	
	POST	11.25	78075	13815	11.25	51356.25	9495	17921.25	8	37640	56460	264762.5	
												642872.5	**6.941322**
			6940	1228		4565	844	1593		4705	4705		
1A-2	FAB	4	27760	4912	6	27390	5064	9558	4	18820	56460	149964	
	IHM	4	27760	4912	9	41085	7596	14337	4	18820	56460	170970	
	POST	8	55520	9824	11.25	51356.25	9495	17921.25	8	37640	56460	238216.5	
												559150.5	**7.980651**
			6940	1228		4565	844	1593		4705	4705		
1A-3	FAB	6	41640	7368	6	27390	5064	9558	4	18820	18820	128660	
	IHM	9	62460	11052	9	41085	7596	14337	4	18820	18820	174170	
	POST	11.25	78075	13815	11.25	51356.25	9495	17921.25	8	37640	18820	227122.5	
												529952.5	**8.420349**
			6940	1228		4565	844	1593		4705	4705		
1A-4	FAB	4	27760	4912	6	27390	5064	9558	4	18820	18820	112324	
	IHM	4	27760	4912	9	41085	7596	14337	4	18820	18820	133330	
	POST	8	55520	9824	11.25	51356.25	9495	17921.25	8	37640	18828	200584.5	
												446238.5	**10**
			6940	1228		4565	844	1593		4705	4705		
1B-1	FAB	28	194320	34384	6	27390	5064	9558	4	18820	56460	345996	
	IHM	28	194320	34384	9	41085	7596	14337	4	18820	56460	367002	
	POST	28	194320	34384	11.25	51356.25	9495	17921.25	8	37640	56460	401576.5	
												1114575	**4.003667**
			6509	1408		4805	554	1593		4705	4705		
2A-1	FAB	6	39054	8448	6	28830	3324	9558	4	18820	56460	164494	
	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												634971.3	**7.027696**
			6509	1408		4805	554	1593		4705	4705		

DESIGN1D.XLS

2A-2	FAB	4	26036	5632	6	28830	3324	9558	4	18820	56460	148660	
	IHM	4	26036	5632	9	43245	4986	14337	4	18820	56460	169516	
	POST	8	52072	11264	11.25	54056.25	6232.5	17921.25	8	37640	56460	235646	
												553822	**8.057435**
			6509	1408		4805	554	1593		4705	4705		
2A-3	FAB	6	39054	8448	6	28830	3324	9558	4	18820	18820	126854	
	IHM	9	58581	12672	9	43245	4986	14337	4	18820	18820	171461	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	18820	223736.3	
												522051.3	**8.547791**
			6509	1408		4805	554	1593		4705	4705		
2B-1	FAB	28	182252	39424	6	28830	3324	9558	4	18820	56460	338668	
	IHM	28	182252	39424	9	43245	4986	14337	4	18820	56460	359524	
	POST	28	182252	39424	11.25	54056.25	6232.5	17921.25	8	37640	56460	393986	
												1092178	**4.085767**
			6591	860		3250	724	6190		4705	4705		
3A-1	FAB	6	39546	5160	6	19500	4344	37140	4	18820	56460	180970	
	IHM	9	59319	7740	9	29250	6516	55710	4	18820	56460	233815	
	POST	11.25	74148.75	9675	11.25	36562.5	8145	69637.5	8	37640	56460	292268.8	
												707053.8	**6.311239**
			6591	860		3250	724	6190		4705	4705		
3A-2	FAB	4	26364	3440	6	19500	4344	37140	4	18820	56460	166068	
	IHM	4	26364	3440	9	29250	6516	55710	4	18820	56460	196560	
	POST	8	52728	6880	11.25	36562.5	8145	69637.5	8	37640	56460	268053	
												630681	**7.075503**
			6591	860		3250	844	6190		4705	4705		
3A-3	FAB	4	26364	3440	6	19500	5064	37140	4	18820	18820	129148	
	IHM	4	26364	3440	9	29250	7596	55710	4	18820	18820	160000	
	POST	8	52728	6880	11.25	36562.5	9495	69637.5	8	37640	18820	231763	
												520911	**8.566502**
			7214	834		3002	810	1593		4705	4705		
4A-1	FAB	6	43284	5004	6	18012	4860	9558	4	18820	56460	155998	
	IHM	9	64926	7506	9	27018	7290	14337	4	18820	56460	196357	
	POST	11.25	81157.5	9382.5	11.25	33772.5	9112.5	17921.25	8	37640	56460	245446.3	
												597801.3	**7.464663**

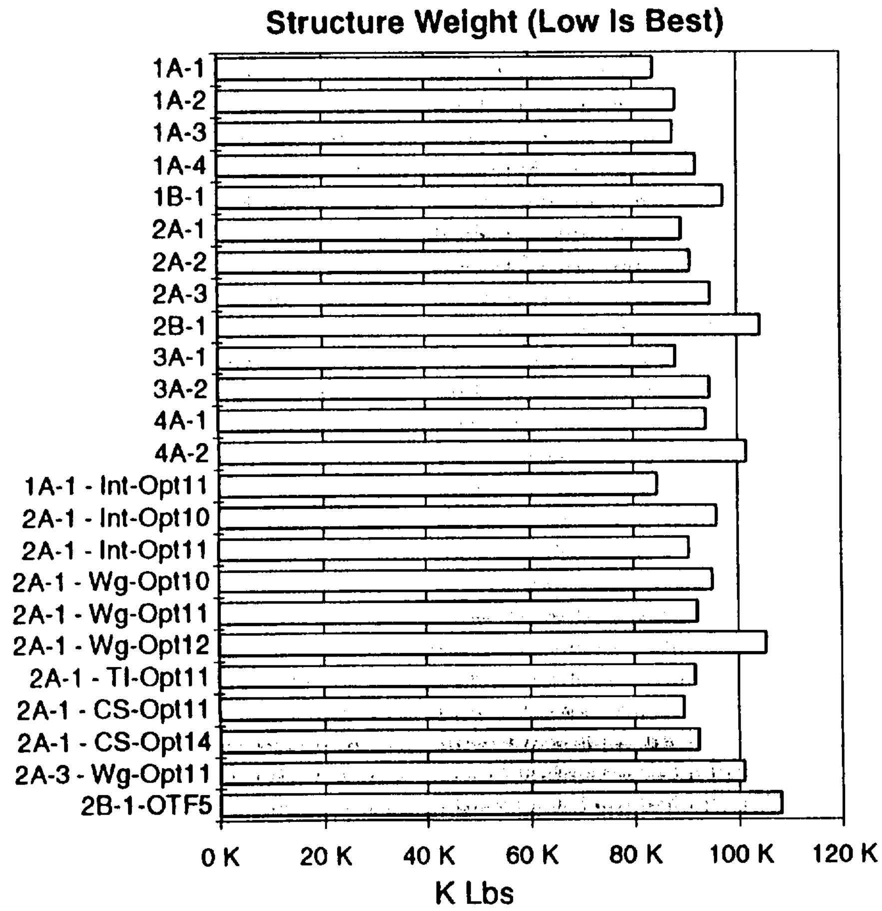
			7214	834		3002	810	1593		4705	4705		
4A-2	FAB	4	28856	3336	6	18012	4860	9558	4	18820	56460	139902	
	IHM	4	28856	3336	9	27018	7290	14337	4	18820	56460	156117	
	POST	8	57712	6672	11.25	33772.5	9112.5	17921.25	8	37640	56460	219290.3	
												515309.3	**8.659625**
			6940	1228		4565	844	1593		4705	4705		
1A-1	FAB	6	41640	7368	6	27390	5064	9558	4	18820	56460	166300	
INT 11	IHM	9	62460	11052	9	41085	7596	14337	4	18820	56460	211810	
	POST	11.25	78075	13815	11.25	51356.25	9495	17921.25	8	37640	56460	264762.5	
												642872.5	**6.941322**
			6509	1408		4805	554	1593		4705	4705		
2A-1	FAB	6	39054	8448	6	28830	3324	9558	4	18820	56460	164494	
INT 10	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												634971.3	**7.027696**
			6509	1408		4805	554	1593		4705	4705		
2A-1	FAB	6	39054	8448	6	28830	3324	9558	4	18820	56460	164494	
INT 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												634971.3	**7.027696**
			6509	1408		4805	554	1593		4705	4705		
2A-1	FAB	6	39054	8448	6	28830	3324	9558	8	37640	56460	183314	
WG 10	IHM	9	58581	12672	9	43245	4986	14337	8	37640	56460	227921	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	16	75280	56460	299016.3	
												710251.3	**6.282826**
			6509	1408		4805	554	1593		4705	4705		
2A-1	FAB	6	39054	8448	6	28830	3324	9558	4	18820	56460	164494	
WG 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												634971.3	**7.027696**
			6509	1408		4805	554	1593		4705	4705		
2A-1	FAB	6	39054	8448	6	28830	3324	9558	8	37640	56460	183314	
WG 12	IHM	9	58581	12672	9	43245	4986	14337	12	56460	56460	246741	

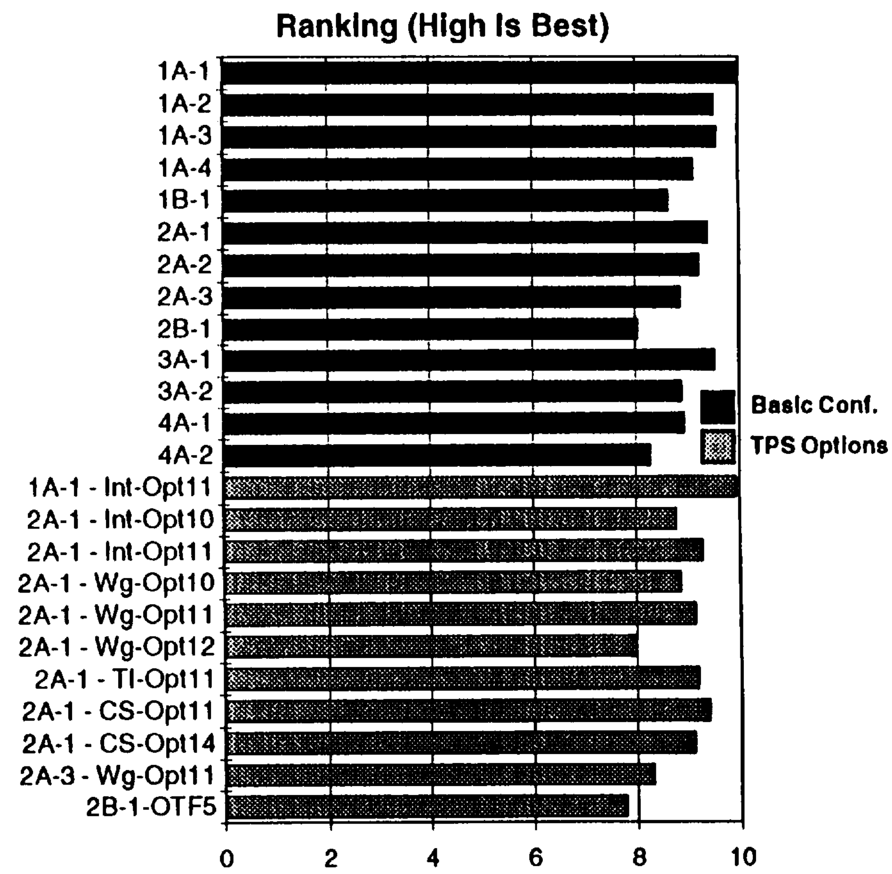
DESIGN1D.XLS

	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	10	47050	56460	270786.3	
												700841.3	**6.367184**
			6509	1408		4805	554	1593		4705	4705		
2A-1	FAB	6	39054	8448	6	28830	3324	9558	4	18820	56460	164494	
TL 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												634971.3	**7.027696**
			6509	1408		4805	554	1593		4705	4705		
2A-1	FAB	6	39054	8448	6	28830	3324	9558	4	18820	56460	164494	
CS 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												634971.3	**7.027696**
			6509	1408		4805	554	1593		4705	4705		
2A-1	FAB	6	39054	8448	6	28830	3324	9558	16	75280	56460	220954	
CS 14	IHM	9	58581	12672	9	43245	4986	14337	12	56460	56460	246741	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	20	94100	56460	317836.3	
												785531.3	**5.680722**
			6509	1408		4805	554	1593		4705	4705		
2A-3	FAB	6	39054	8448	6	28830	3324	9558	4	18820	18820	126854	
WG 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	18820	171461	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	18820	223736.3	
												522051.3	**8.547791**
			6509	1408		4805	554	1593		4705	4705		
2B-1	FAB	28	182252	39424	6	28830	3324	9558	28	131740	56460	451588	
OTF 5	IHM	28	182252	39424	9	43245	4986	14337	28	131740	56460	472444	
	POST	28	182252	39424	11.25	54056.25	6232.5	17921.25	28	131740	56460	488086	
												1412118	**3.160065**

1A-1 And 1A-1 Intertank Options Have Lowest Primary Structure Weights

2a. Primary structure weight- (Quantitative evaluation) - The candidate vehicle options are rated according to the determined total structure weight.





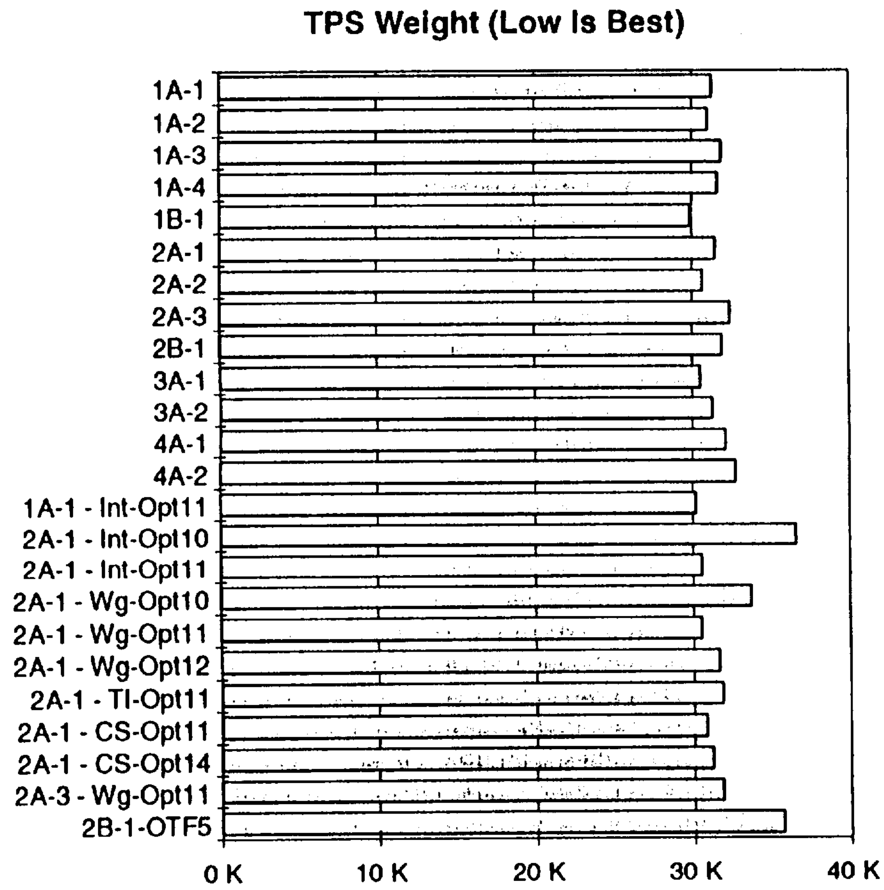
Jan 24 Certification matrix

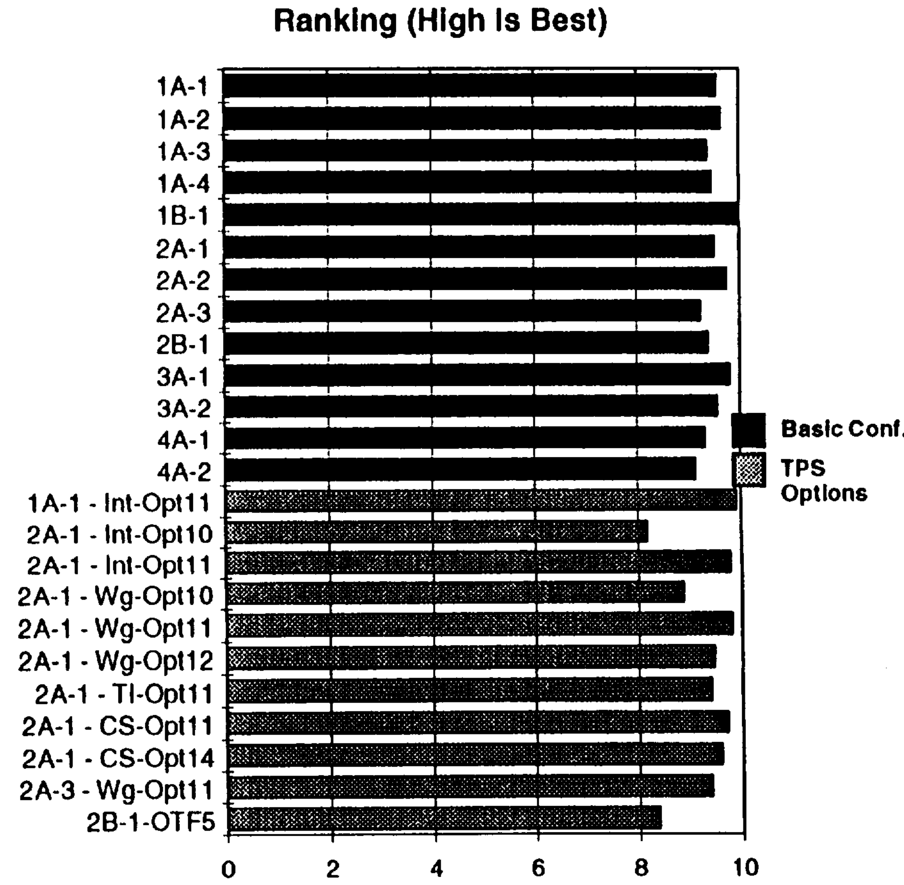
Option	Primry struct Wght (k)		SC-2a Primary structure weight
1A-1	83,976		
1A -2	88,211		
1A-3	87,738		
1A-4	92,143		
1B-1	97,308		
2A-1	89,339		
2A-2	91,070		
2A-3	94,865		
2B-1	104,426		
3A-1	88,259		
3A-2	94,617		
4A-1	94,005		
4A-2	101,617		
1A-1-Int-Opt 11	84,508		
2A-1-Int-Opt 10	95,886		
2A-1-Int-Opt 11	90,601		
2A-1-Wng-Opt 10	94,990		
2A-1-Wng-Opt 11	92,104		
2A-1-Wng-Opt 12	105,371		
2A-1-Tail-Opt 11	91,618		
2A-1-CS-Opt 11	89,387		
2A-1-CS-Opt 14	92,258		
2A-3-Wng-Opt 11	101,000		
2B-1-OTF5	108,074		

1B-1 And 1A-1 Intertank Options Option Have Lowest TPS Weights

SSTO

2b. TPS weight - (Quantitative evaluation) - The candidate vehicle options are rated according to the determined total TPS structure weight.





NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

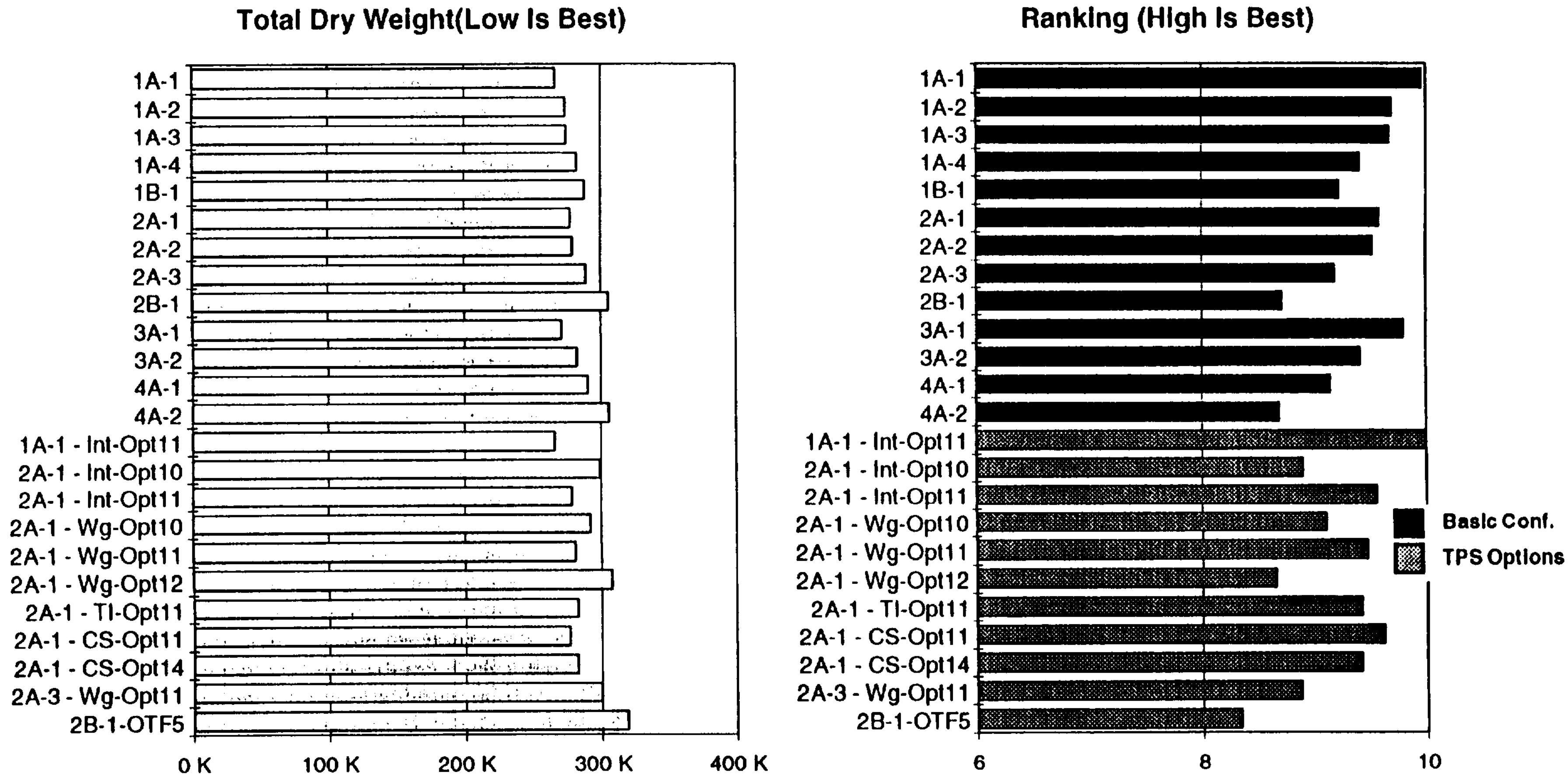
Jan 24 Certification matrix

Option	TPS Wght (k)	SC-2b TPS weight
1A-1	31,283	
1A -2	31,023	
1A-3	31,889	
1A-4	31,631	
1B-1	29,909	
2A-1	31,477	
2A-2	30,706	
2A-3	32,421	
2B-1	31,926	
3A-1	30,526	
3A-2	30,314	
4A-1	32,132	
4A-2	32,779	
1A-1-Int-Opt 11	30,200	
2A-1-Int-Opt 10	36,598	
2A-1-Int-Opt 11	30,591	
2A-1-Wng-Opt 10	33,738	
2A-1-Wng-Opt 11	30,524	
2A-1-Wng-Opt 12	31,675	
2A-1-Tail-Opt 11	31,850	
2A-1-CS-Opt 11	30,808	
2A-1-CS-Opt 14	31,218	
2A-3-Wng-Opt 11	31,831	
2B-1-OTF5	35,689	

1A-1 And 1A-1 Intertank Options Have Lowest Vehicle Dry Weights

SSTO

2c. Total dry weight - (Quantitative evaluation) - The candidate vehicle options are rated according to the determined total Vehicle dry weight.



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Jan 24 Certification matrix

SC-2c Total Dry weight

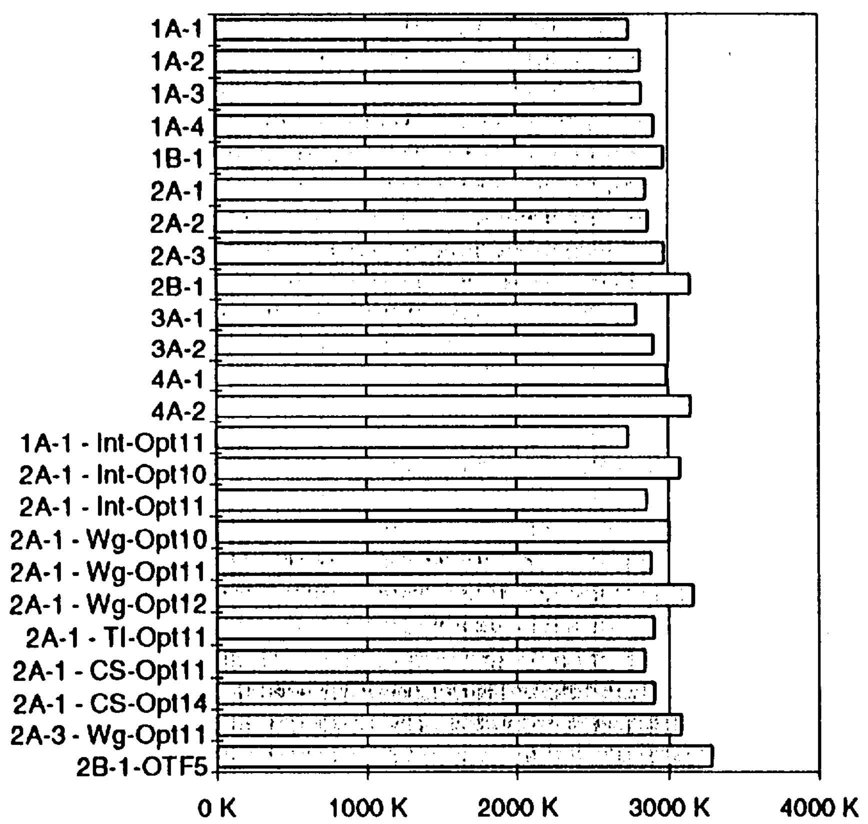
Option	Total Dry Wght (k)
1A-1	266,966
1A -2	274,250
1A-3	274,970
1A-4	282,567
1B-1	288,326
2A-1	277,610
2A-2	279,371
2A-3	289,480
2B-1	305,336
3A-1	271,367
3A-2	282,539
4A-1	290,816
4A-2	306,130
1A-1-Int-Opt 11	265,957
2A-1-Int-Opt 10	299,013
2A-1-Int-Opt 11	278,301
2A-1-Wng-Opt 10	292,125
2A-1-Wng-Opt 11	280,936
2A-1-Wng-Opt 12	307,375
2A-1-Tail-Opt 11	282,477
2A-1-CS-Opt 11	276,470
2A-1-CS-Opt 14	282,491
2A-3-Wng-Opt 11	299,649
2B-1-OTF5	318,894

1A-1 And 1A-1 Intertank Options Have Lowest Vehicle Gross Fueled Weights

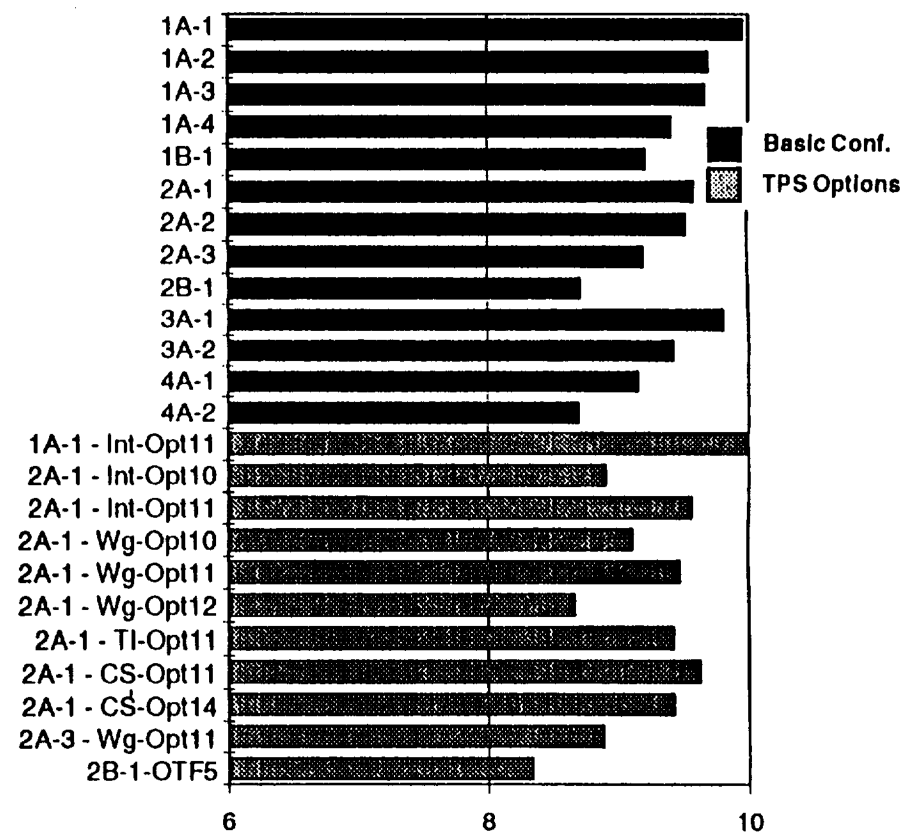
SSTO

3a. Gross fueled weight sensitivity - Quantitative Evaluation - The candidate vehicle options are rated according to the determined gross vehicle weight.

Total Dry Weight(Low Is Best)



Ranking (High Is Best)



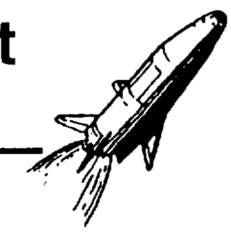
NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Jan 24 Certification matrix

SC-3 Gross fueled weight sensitivity

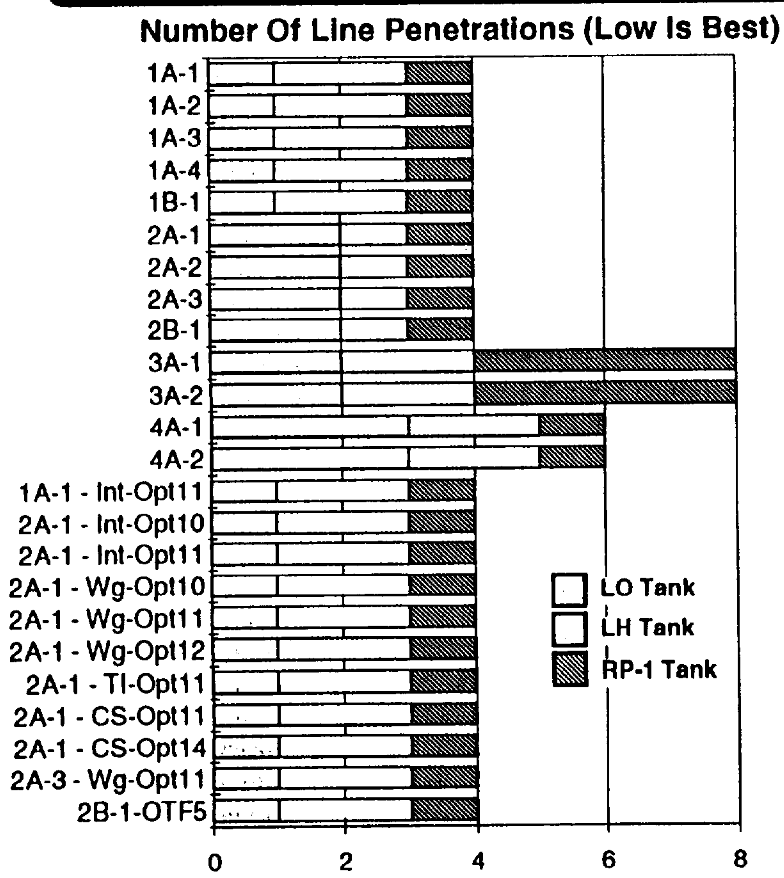
Option	Gross Weight
1A-1	2,747,652
1A -2	2,822,725
1A-3	2,830,145
1A-4	2,908,441
1B-1	2,971,125
2A-1	2,854,344
2A-2	2,872,477
2A-3	2,976,545
2B-1	3,141,733
3A-1	2,789,767
3A-2	2,904,785
4A-1	2,989,246
4A-2	3,146,905
1A-1-Int-Opt 11	2,737,250
2A-1-Int-Opt 10	3,074,685
2A-1-Int-Opt 11	2,861,456
2A-1-Wng-Opt 10	3,003,773
2A-1-Wng-Opt 11	2,888,590
2A-1-Wng-Opt 12	3,160,776
2A-1-Tail-Opt 11	2,904,452
2A-1-CS-Opt 11	2,842,613
2A-1-CS-Opt 14	2,904,590
2A-3-Wng-Opt 11	3,081,233
2B-1-OTF5	3,281,313

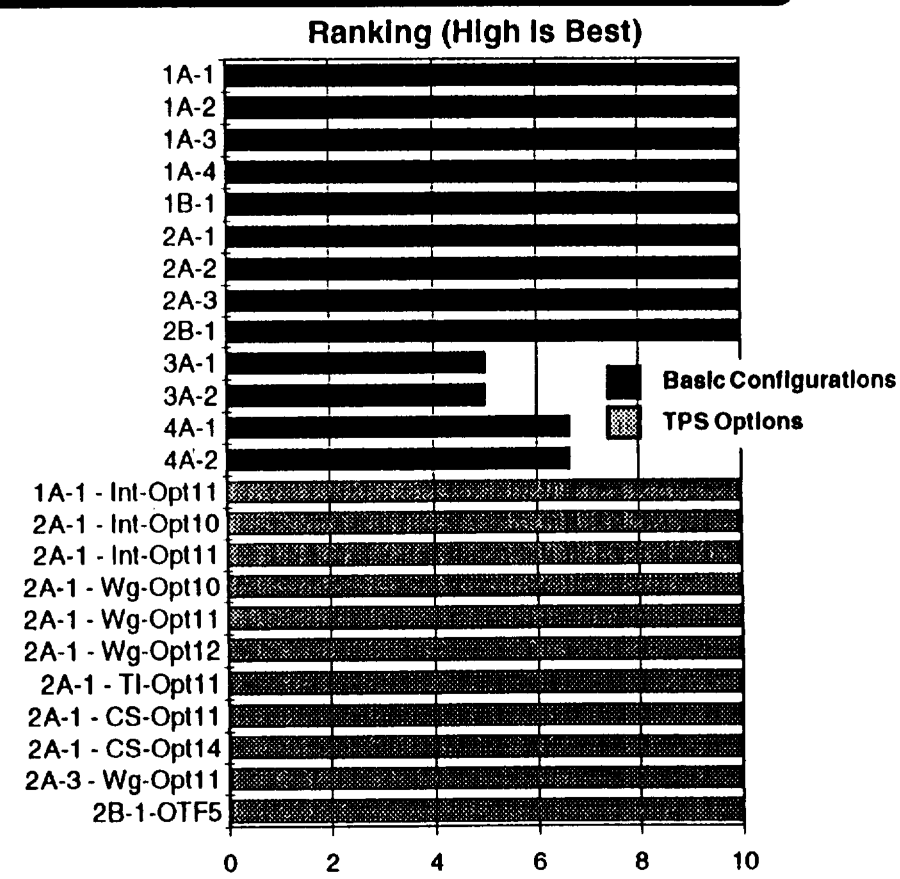
1A, 2A, And 2B Options Ranked Best For Lowest Number of Feed Line Tank Penetrations



SSTO

4a. Number of feed line tank penetrations - (Quantitative evaluation) - The candidate vehicle options are compared on the basis of the number of penetrations required for the propellant feed system. Included in this comparison is whether internal or external sumps are required, and if so how many.





Jan 24 Certification matrix

SC-4a Number of line penetrations

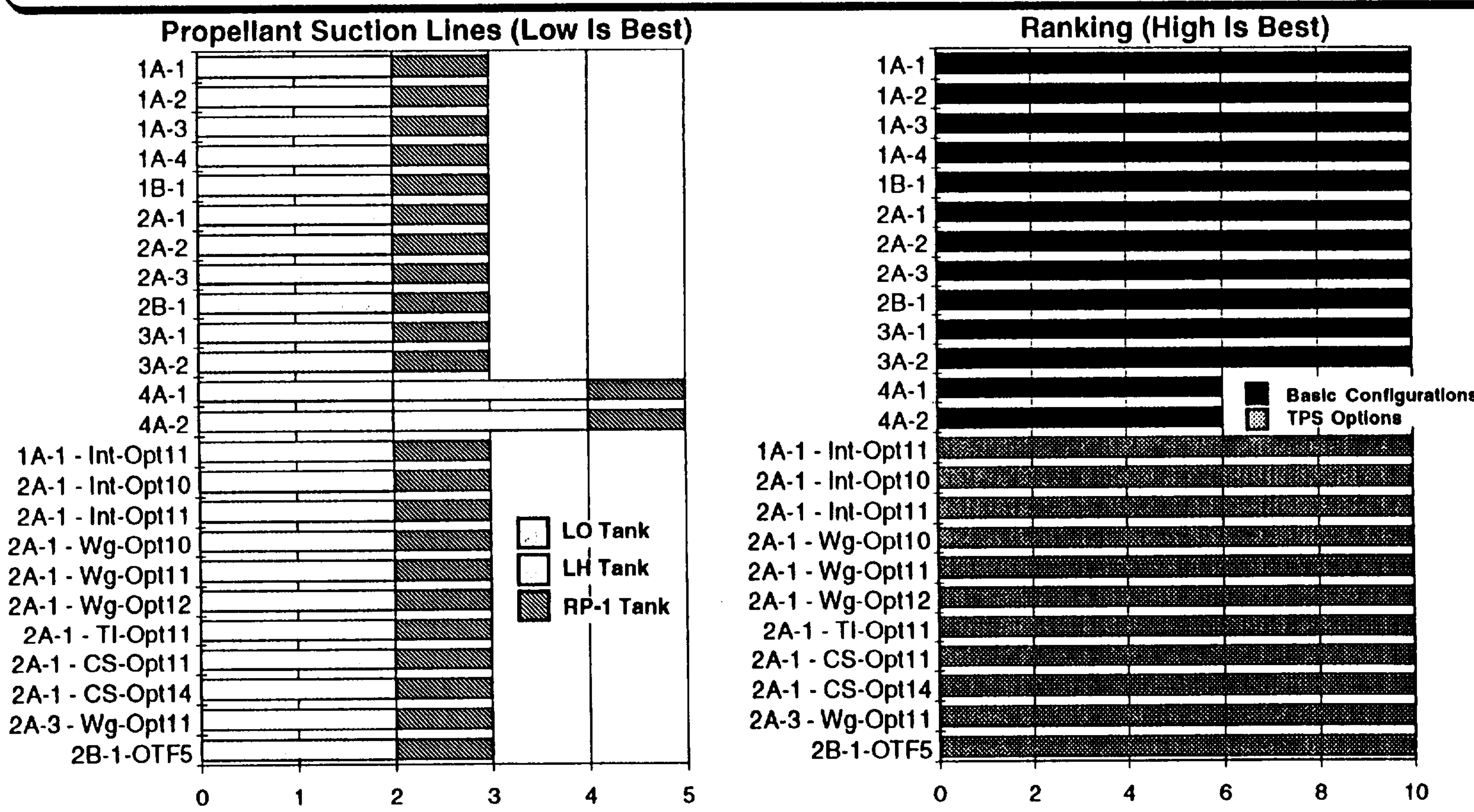
Values within are fictitious and for example only

Option	LO Tank	LH Tank	RP tank	Total scor
1A-1	1	2	1	4
1A -2	1	2	1	4
1A-3	1	2	1	4
1A-4	1	2	1	4
1B-1	1	2	1	4
2A-1	2	1	1	4
2A-2	2	1	1	4
2A-3	2	1	1	4
2B-1	2	1	1	4
3A-1	2	2	4	8
3A-2	2	2	4	8
4A-1	3	2	1	6
4A-2	3	2	1	6
1A-1-Int-Opt 10	1	2	1	4
2A-1-Int-Opt 10	1	2	1	4
2A-1-Int-Opt 11	1	2	1	4
2A-1-Wng-Opt 10	1	2	1	4
2A-1-Wng-Opt 11	1	2	1	4
2A-1-Wng-Opt 12	1	2	1	4
2A-1-Tail-Opt 11	1	2	1	4
2A-1-CS-Opt 11	1	2	1	4
2A-1-CS-Opt 14	1	2	1	4
2A-3-Wng-Opt 11	1	2	1	4
2B-1-OTF5	1	2	1	4

4A Options Ranked Worst - Largest Number of Propellant Suction Lines

SSTO

4b. Number of propellant suction lines - (Quantitative evaluation) - The candidate vehicle options are compared on the basis of the number of propellant suction lines (similar in principle to that used on the STS-ET LH2 tank) which penetrate the tank. The use of suction lines, though offering advantages in intertank length, results in additional complexity feed system design and operational complexity due to the incorporation of high point bleeds.



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Jan 24 Certification matrix

			SC-4b Number of propellant suction lines	
Option	LO Tank	LH Tank	RP tank	Total scor
1A-1	0	2	1	3
1A -2	0	2	1	3
1A-3	0	2	1	3
1A-4	0	2	1	3
1B-1	0	2	1	3
2A-1	2	0	1	3
2A-2	2	0	1	3
2A-3	2	0	1	3
2B-1	2	0	1	3
3A-1	0	2	1	3
3A-2	0	2	1	3
4A-1	2	2	1	5
4A-2	2	2	1	5
1A-1-Int-Opt 10	0	2	1	3
2A-1-Int-Opt 10	0	2	1	3
2A-1-Int-Opt 11	0	2	1	3
2A-1-Wng-Opt 10	0	2	1	3
2A-1-Wng-Opt 11	0	2	1	3
2A-1-Wng-Opt 12	0	2	1	3
2A-1-Tail-Opt 11	0	2	1	3
2A-1-CS-Opt 11	0	2	1	3
2A-1-CS-Opt 14	0	2	1	3
2A-3-Wng-Opt 11	0	2	1	3
2B-1-OTF5	0	2	1	3

4A Options Ranked Best For Ease Of Integrating Propellant Slosh Baffles Within The Tank

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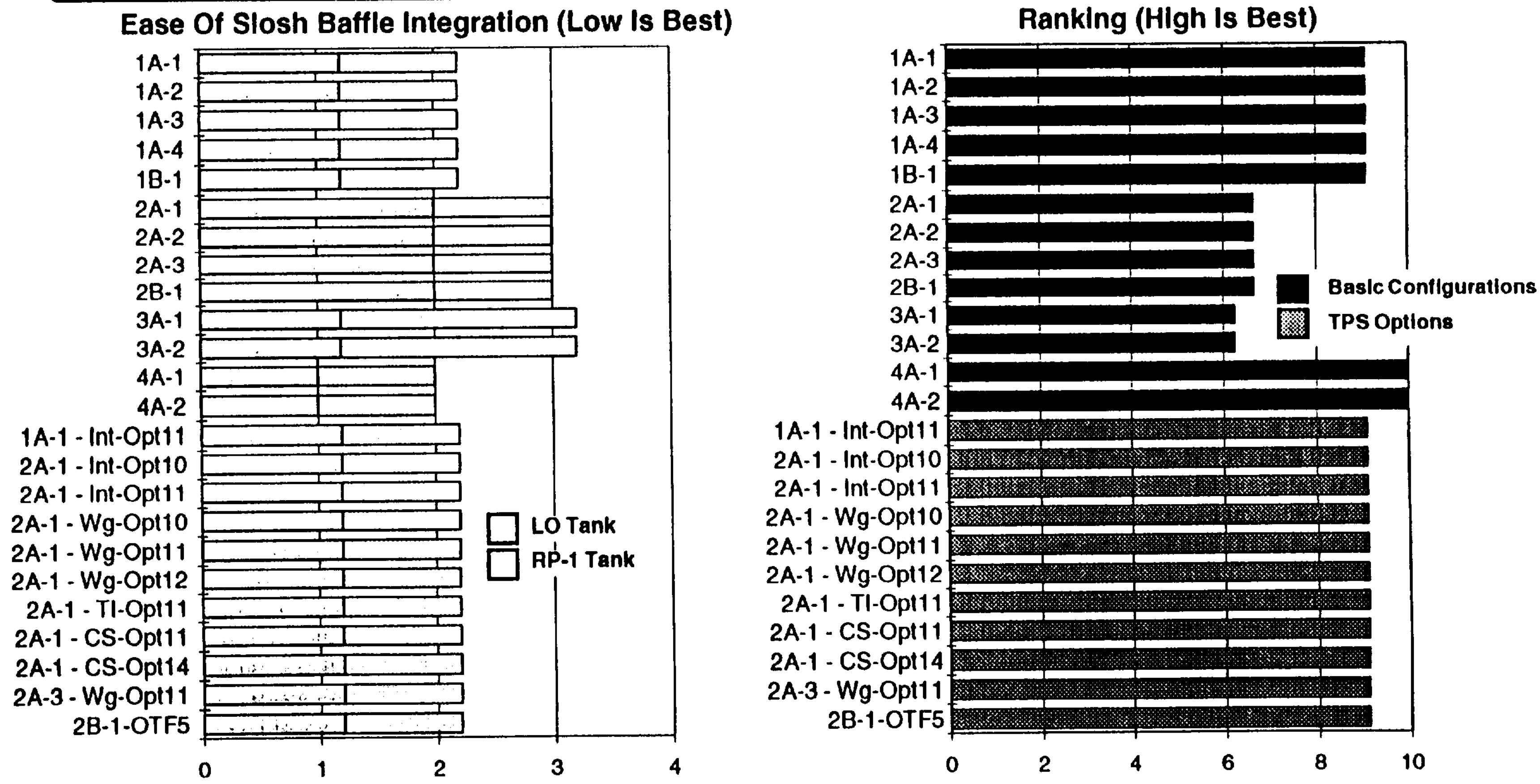
4c. Ease of integrating propellant slosh baffles within the tank - (Qualitative evaluation) - The candidate vehicle options are rated according to the fabrication process and degree of difficulty associated with fabricating and installing propellant slosh baffles to the inside tank walls.



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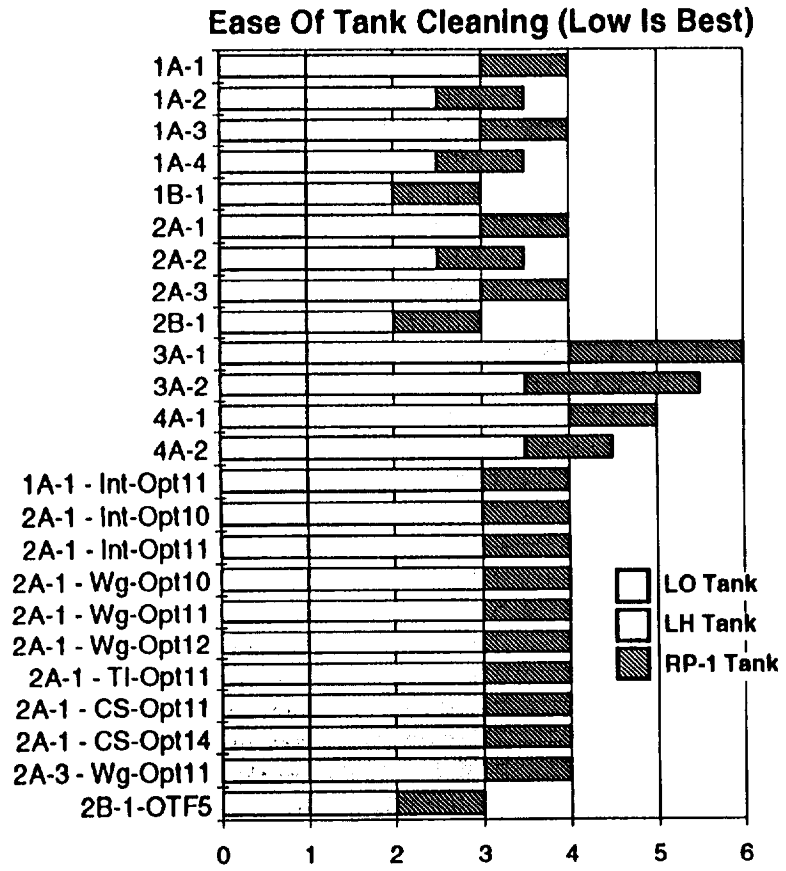
Jan 24 Certification matrix

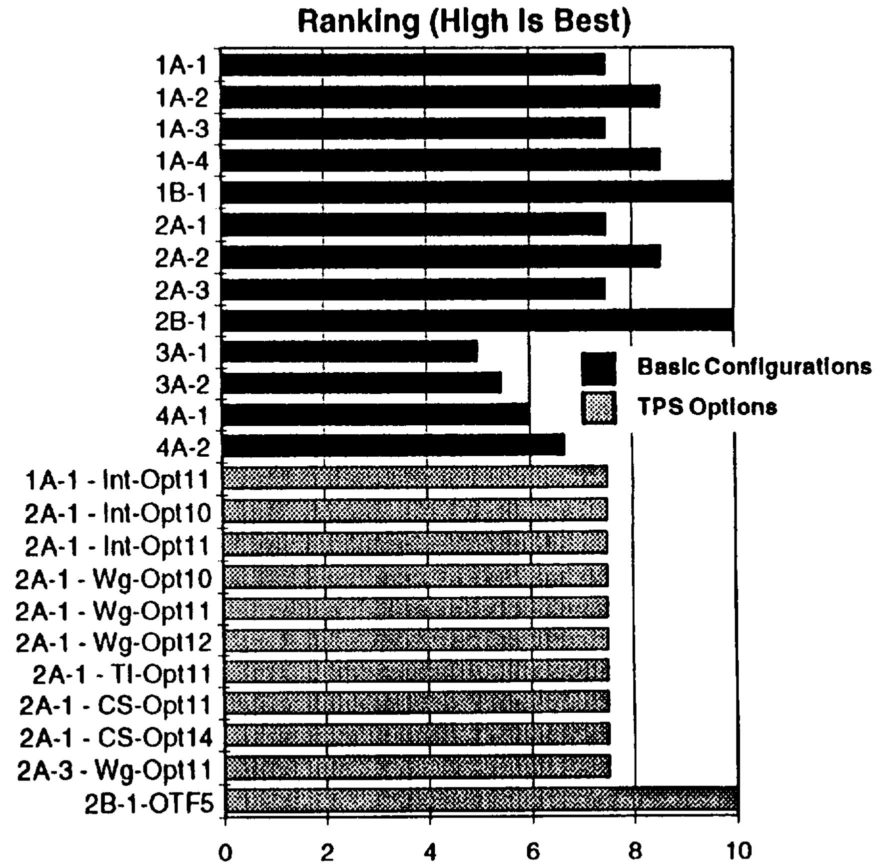
SC-4c Ease of slosh baffle integration

Option	LO Tank	LH Tank	RP tank	Total scor
1A-1	1.2	0	1	2.2
1A -2	1.2	0	1	2.2
1A-3	1.2	0	1	2.2
1A-4	1.2	0	1	2.2
1B-1	1.2	0	1	2.2
2A-1	2	0	1	3
2A-2	2	0	1	3
2A-3	2	0	1	3
2B-1	2	0	1	3
3A-1	1.2	0	2	3.2
3A-2	1.2	0	2	3.2
4A-1	1	0	1	2
4A-2	1	0	1	2
1A-1-Int-Opt 10	1.2	0	1	2.2
2A-1-Int-Opt 10	1.2	0	1	2.2
2A-1-Int-Opt 11	1.2	0	1	2.2
2A-1-Wng-Opt 10	1.2	0	1	2.2
2A-1-Wng-Opt 11	1.2	0	1	2.2
2A-1-Wng-Opt 12	1.2	0	1	2.2
2A-1-Tail-Opt 11	1.2	0	1	2.2
2A-1-CS-Opt 11	1.2	0	1	2.2
2A-1-CS-Opt 14	1.2	0	1	2.2
2A-3-Wng-Opt 11	1.2	0	1	2.2
2B-1-OTF5	1.2	0	1	2.2

Options 1B and 2B Ranked Best For Ease Of Tank Cleaning

4d. Ease of tank cleaning - (Qualitative evaluation) - The candidate vehicle options are rated according to the complexity associated with cleaning the propellant tanks with non-freon based chemicals following both initial tank fabrication, and subsequent maintenance activities within the tank.





Jan 24 Certification matrix

SC-4d Ease of tank cleaning

Values within are fictitious and for example only

Option	LO Tank	LH Tank	RP tank	Total scor
1A-1	1	2	1	4
1A -2	1	1.5	1	3.5
1A-3	1	2	1	4
1A-4	1	1.5	1	3.5
1B-1	1	1	1	3
2A-1	1	2	1	4
2A-2	1	1.5	1	3.5
2A-3	1	2	1	4
2B-1	1	1	1	3
3A-1	1	3	2	6
3A-2	1	2.5	2	5.5
4A-1	1	3	1	5
4A-2	1	2.5	1	4.5
1A-1-Int-Opt 10	1	2	1	4
2A-1-Int-Opt 10	1	2	1	4
2A-1-Int-Opt 11	1	2	1	4
2A-1-Wng-Opt 10	1	2	1	4
2A-1-Wng-Opt 11	1	2	1	4
2A-1-Wng-Opt 12	1	2	1	4
2A-1-Tail-Opt 11	1	2	1	4
2A-1-CS-Opt 11	1	2	1	4
2A-1-CS-Opt 14	1	2	1	4
2A-3-Wng-Opt 11	1	2	1	4
2B-1-OTF5	1	1	1	3

2A And 2B Options Ranked Best For Highest % Margin At Lift Off (Ascent Controllability)

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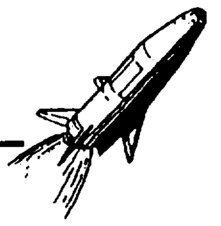
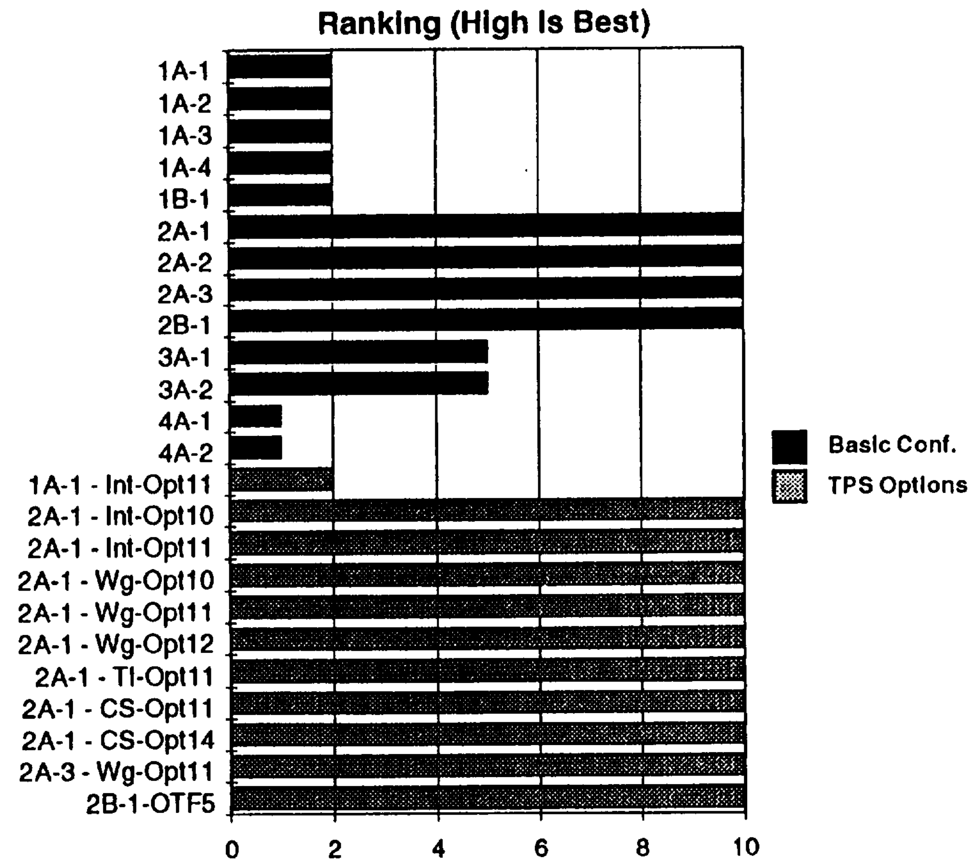


5a. Ascent controllability- (Quantitative evaluation) - The candidate vehicle options are compared on the basis of ascent controllability provided by engine thrust vector control and vehicle characteristics.



Controllability Rankings

Configuration Option	Rankings: Ascent Controllability	Rankings: Hypersonic Aerodynamic Controllability	Rankings: Subsonic Aerodynamic Controllability
	@ Max qa	aero @ entry & landing	aero @ entry & landing
	(largest margin=10 least margin=1)	(least unstable=10 most unstable=1)	(least stable=10 most stable=1)
1	2	1	1
2	10	10	10
3	5	10	10
4	1	1	1

Options 2 Ranked Best For Hypersonic Controllability

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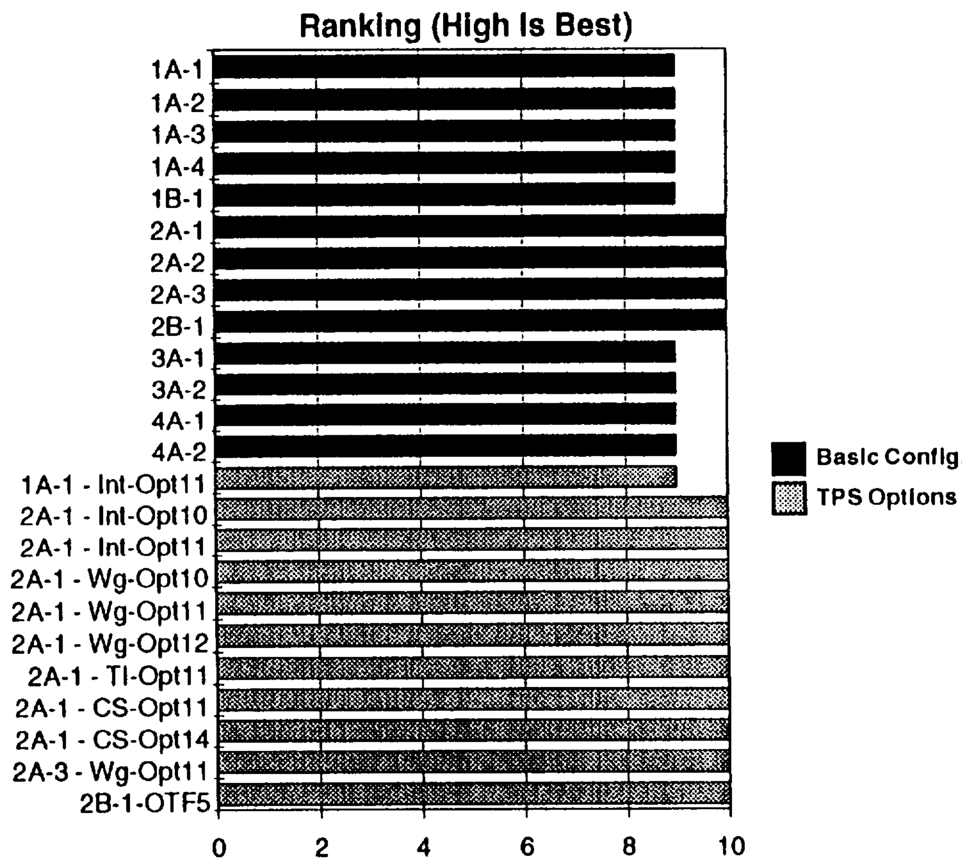
5b. Hypersonic controllability- (Qualitative evaluation) - The candidate vehicle options are compared on the basis of hypersonic controllability during entry.



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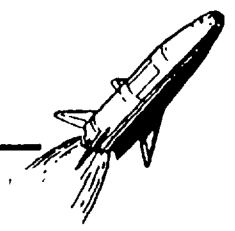
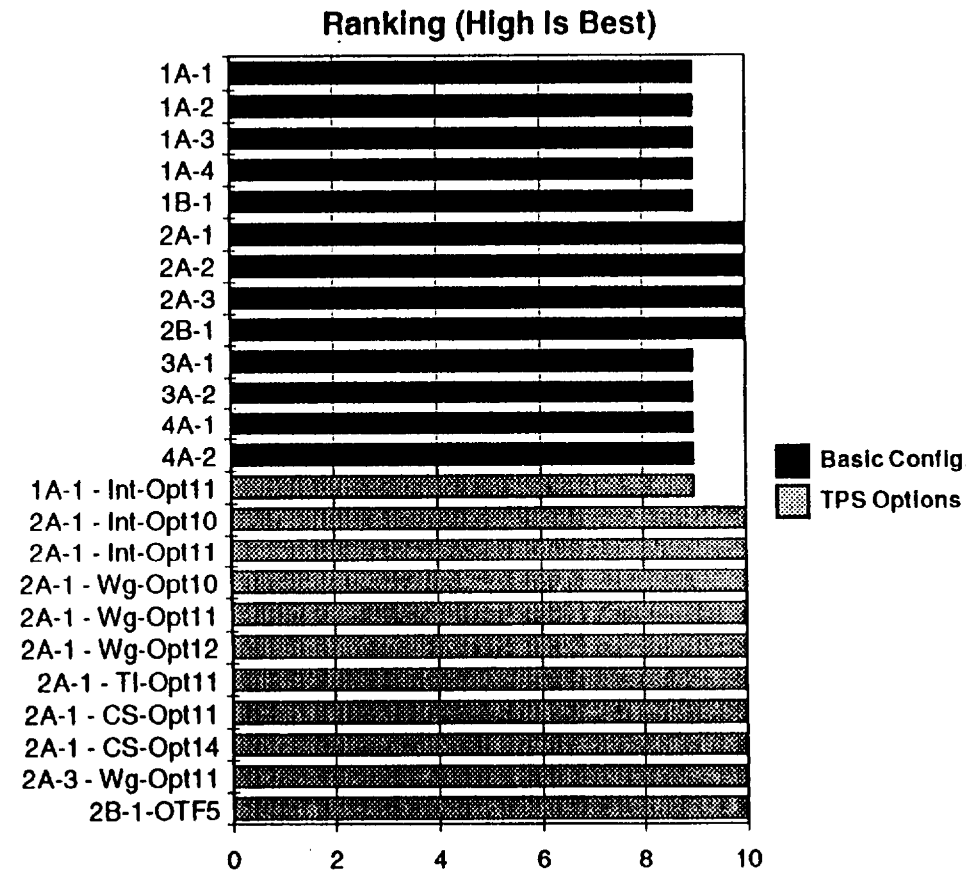
Controllability Rankings

	Rankings		
Configuration Option	Ascent Controllability	Hypersonic Aerodynamic Controllability	Subsonic Aerodynamic Controllability
	@ Max qa	aero @ entry & landing	aero @ entry & landing
	(largest margin=10 least margin=1)	(least unstable=10 most unstable=1)	(least stable=10 most stable=1)
1	2	1	1
2	10	10	10
3	5	10	10
4	1	1	1

Options 2 Ranked Best For Subsonic Controllability



5c. Subsonic controllability - (Qualitative evaluation) - The candidate vehicle options are compared on the basis of subsonic controllability during entry.



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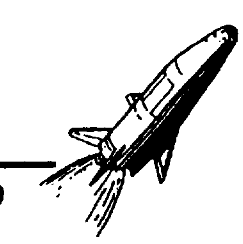
Controllability Rankings

Configuration Option	Rankings		
	Ascent Controllability	Hypersonic Aerodynamic Controllability	Subsonic Aerodynamic Controllability
	@ Max qa	aero @ entry & landing	aero @ entry & landing
	(largest margin=10 least margin=1)	(least unstable=10 most unstable=1)	(least stable=10 most stable=1)
1	2	1	1
2	10	10	10
3	5	10	10
4	1	1	1

On Pad And Maintenance Operations Analysis Performed By Downey And KSC LSS Personnel

Operations	Mary Manley - RI Downey Advanced Programs Chuck Urrutia - RI KSC Advanced Programs
TPS Operations	Mike Gordon - RI KSC LSS
Propulsion	Steve Coester - RI KSC LSS Steve Petrilla - RI Downey Propulsion
IVHM	Edward Litwinski

Option 1 And 2B Received Highest Ranking - Parallel Fueling Results In Lowest Fueling Time



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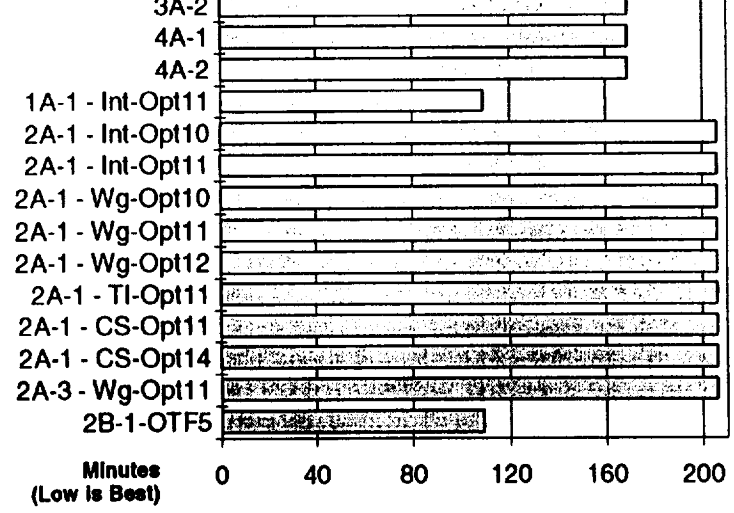
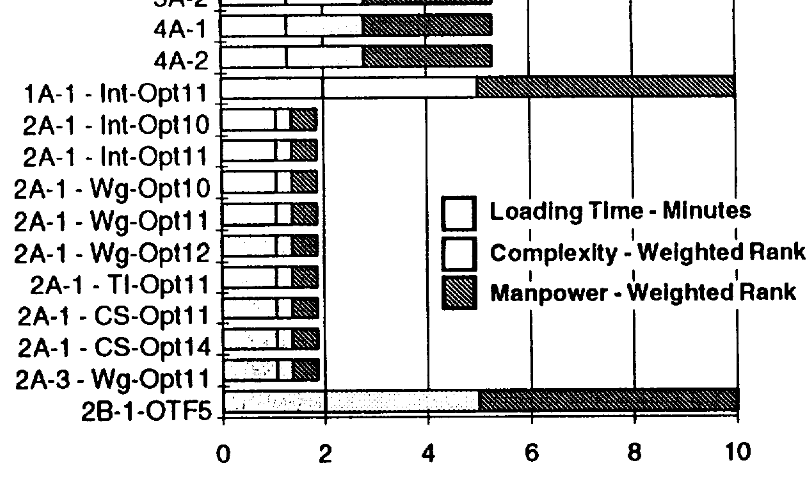
6a. Tank pressurization /depressurization and fueling/draining timelines- (Quantitative and Qualitative evaluation) - The candidate vehicle options are compared on the basis of the complexity of the systems (qualitative) and the time lines required to fill and pressurize the main propellant tanks (quantitative).





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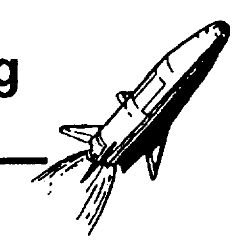
Tank Pressurization/ Depressurization and Fueling/Draining Based On Duration, Complexity And Manpower



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Fueling	Duration	Complexity	Manpower Rating
Parallel	109 Minutes	Least Complex	Low
Serial	206 Minutes	Most Complex	High
Common Bulkhead	169 Minutes	Complex	Medium

LH2 Fueling Timeline

SSTO/Facility Chill	4 Min *
Slow Fill	7 Min
Fast Fill	31 Min
Topping	7 Min
Replenish/Stabilization	60 Min
Total	109 Min

LO2 Fueling Timeline

Facility Chill	12 Min
Slow Fill	2 Min
Fast Fill	21 Min
Topping	2 Min
Replenish/Stabilization	60 Min
Total	97 Min

RP-1 Fueling Timeline

Slow Fill	10 Min
Fast Fill	40 Min
Topping	10 Min
Total	60 Min

Notes:

* **Common Bulkhead** - Requires Thermal Conditioning Of Common Bulkhead (Additional 60 Minutes)

Serial Loading (Configurations 2A) - Requires Precise Pressurization Control & Safing Systems
Requires Refrigeration Of LH2 System

Draining - Performed In Approximately The Same Amount Of Time As Fueling

Ranking Calculated Based On Fueling For Serial, Parallel Or Common Bulkhead, And Manpower And Complexity

SSTO

Configuration Data	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3	4A-1	4A-2	1A-1 - Int-Opt11	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - Tl-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
LO2	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662	27662
LH2	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432	43432
RP1	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200
Type Load (P - Parallel, S - Serial, B - Common Bulkhead)	P	P	P	P	P	S	S	S	P	B	B	B	B	B	P	S	S	S	S	S	S	S	S	S	P

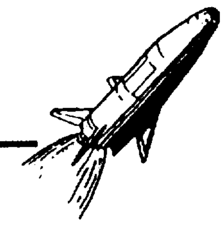
Timeline Results	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3	4A-1	4A-2	1A-1 - Int-Opt11	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - Tl-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
Minutes	109	109	109	109	109	206	206	206	109	169	169	169	169	169	109	206	206	206	206	206	206	206	206	206	109
Timeline - Ranking	10.0	10.0	10.0	10.0	10.0	5.3	5.3	5.3	10.0	6.4	6.4	6.4	6.4	6.4	10.0	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	10.0
Manpower - Rank	10.0	10.0	10.0	10.0	10.0	1.0	1.0	1.0	10.0	5.0	5.0	5.0	5.0	5.0	10.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	10.0
Complexity - Rank	10.0	10.0	10.0	10.0	10.0	1.0	1.0	1.0	10.0	5.0	5.0	5.0	5.0	5.0	10.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	10.0

Weighting
Timeline - 20%
Manpower - 30%
Complexity - 50%

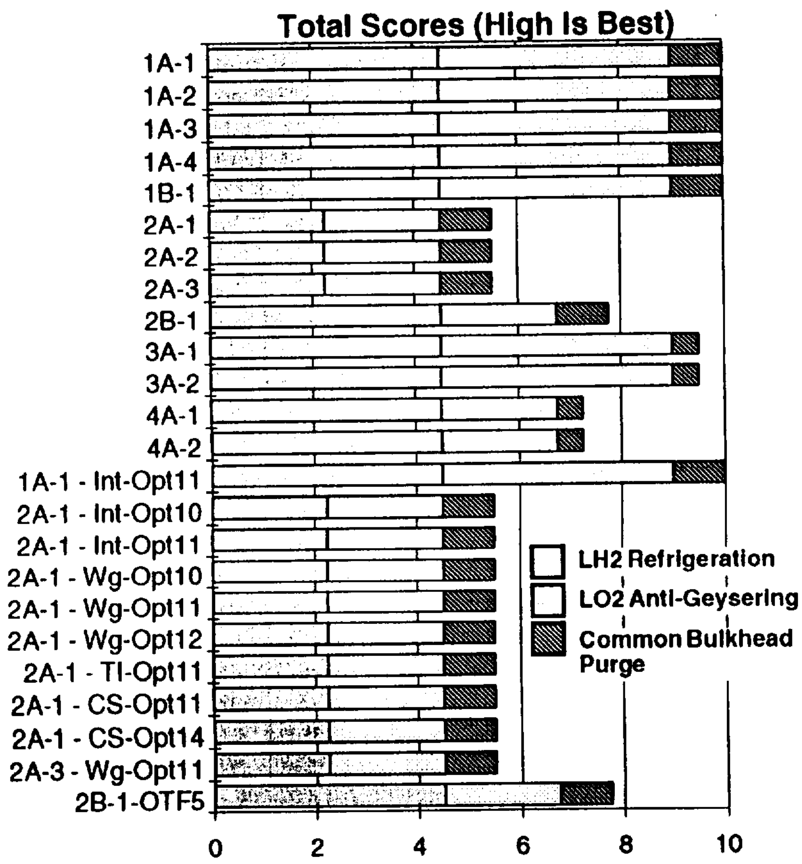
Results	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3	4A-1	4A-2	1A-1 - Int-Opt11	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - Tl-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
Ranking	10.0	10.0	10.0	10.0	10.0	1.9	1.9	1.9	10.0	5.3	5.3	5.3	5.3	5.3	10.0	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	10.0

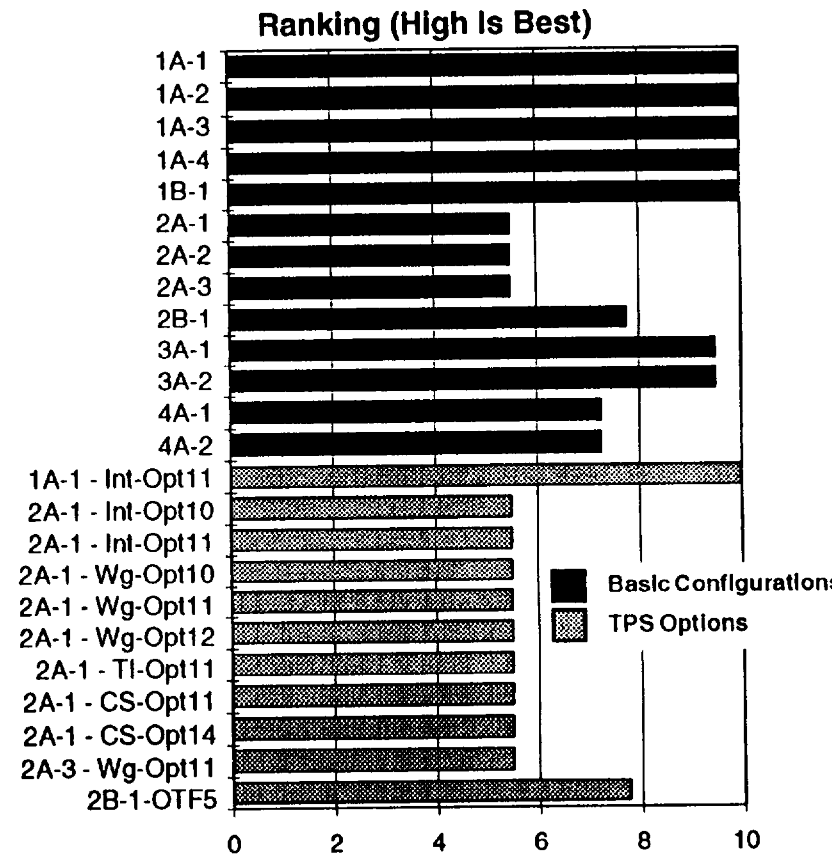
Option 1 Ranked Best For Fewest Additional Subsystems Required For On Pad Operations

SSTO



6b. Subsystems for on pad operations - (Quantitative evaluation) - The candidate vehicle options are compared on the basis of the additional on pad systems necessary to support launch. The scoring will include a complexity factor applied to the additional systems. A purging system for frost avoidance is an example of such a system.





Additional On Pad Subsystems

On-Pad Subsystems

LH2 Refrigeration

Configurations 2A-1, -2, and -3 require the use of a refrigeration subsystem. In these configurations, the LH2 tank will be loaded and pressurized before the LO2 tank is loaded. LH2 at the top of the tank will become warm. This warm LH2 must either vented and new cold LH2 pumped in, or the warm LH2 may be returned to an on-ground refrigeration system to chill it and return it to the LH2 tank. This system is not required for other configurations where the LH2 and LO2 are loaded in parallel.
Requires - Disconnect for incoming propellant, vent line, line for removal of LH2, on-ground refrigeration system

Score 10 - no recirculation subsystem required
1 - recirculation subsystem required

LO2 Anti-geysering Subsystem

Geysering is a problem for vehicles with LO2 Tanks forward. Long cryogenic feed lines lines are required. Heating of the lower portion of cryogenic feed lines causes vaporization of some of the liquid. Resulting bubbles rise, expand, and eventually coalesce into a single entity called a Taylor bubble which fills the complete diameter of the line. The bubble rises, expelling liquid ahead of i from the line into the tank. When the bubble enters the tank, it rises through the liquid into the ullage. Cold liquid at the bottom of the tank rushes into the empty line propelled by gravity and the low pressure ahead of it created by condensation of the vapor in th line. The column of liquid impacts a closed valve or other obstruction at the bottom of the line with sufficiently high velocity to create a potentially destructive water hammer surge pressure.

Score 10 - no anti-geysering subsystem required
1 - anti-geysering subsystem required (relative forward position of LO2 tank is not a discriminator)

GSE Purge For Common Bulkhead

During propellant loading, nitrogen flows between the LO2 and LH2 tanks. Composition of the outgoing nitrogen is measured to determine if there is any leakage between the LH2 and LO2 tanks.

Score 10 - no common bulkhead subsystem required
1 - common bulkhead subsystem required

Nitrogen Purge System

Required for all configurations - Not a discriminator

Complexity (% comparison)

LH2 Recirculation	45%
LO2 Antigeysering	45%
GSE Purge System	10%
Nitrogen Purge	0%

Additional On Pad Subsystems

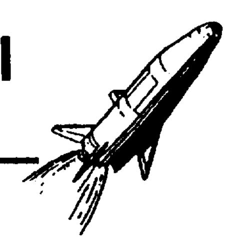
Configuration		1A-1		1A-2		1A-3		1A-4		1B-1		2A-1		2A-2		2A-3		2B-1	
Selection Criteria	Wt	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
LH2 Recirculation	45%	10.0	4.5	10.0	4.5	10.0	4.5	10.0	4.5	10.0	4.5	5.0	2.3	5.0	2.3	5.0	2.3	10.0	4.5
LO2 Antigeysering	45%	10.0	4.5	10.0	4.5	10.0	4.5	10.0	4.5	10.0	4.5	5.0	2.3	5.0	2.3	5.0	2.3	5.0	2.3
GSE Purge System	10%	10.0	1.0	10.0	1.0	10.0	1.0	10.0	1.0	10.0	1.0	10.0	1.0	10.0	1.0	10.0	1.0	10.0	1.0
Nitrogen Purge	-																		
Total Wt'd Score	100%		10.0		10.0		10.0		10.0		10.0		5.5		5.5		5.5		7.8
Ranking			10		10		10		10		10		1		1		1		6

Configuration		3A-1		3A-2		3A-3		4A-1		4A-2		1A-1 - Int-Opt11		2A-1 - Int-Opt10		2A-1 - Int-Opt11	
Selection Criteria	Wt	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
LH2 Recirculation	45%	10.0	4.5	10.0	4.5	10.0	4.5	10.0	4.5	10.0	4.5	10.0	4.5	5.0	2.3	5.0	2.3
LO2 Antigeysering	45%	10.0	4.5	10.0	4.5	10.0	4.5	5.0	2.3	5.0	2.3	10.0	4.5	5.0	2.3	5.0	2.3
GSE Purge System	10%	5.0	0.5	5.0	0.5	5.0	0.5	5.0	0.5	5.0	0.5	10.0	1.0	10.0	1.0	10.0	1.0
Nitrogen Purge	-																
Total Wt'd Score	100%		9.5		9.5		9.5		7.3		7.3		10.0		5.5		5.5
Ranking			9		9		9		5		5		10		1		1

Configuration		2A-1 - Wg-Opt10		2A-1 - Wg-Opt11		2A-1 - Wg-Opt12		2A-1 - Tl-Opt11		2A-1 - CS-Opt11		2A-1 - CS-Opt14		2A-3 - Wg-Opt11	
Selection Criteria	Wt	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
LH2 Recirculation	45%	5.0	2.3	5.0	2.3	5.0	2.3	5.0	2.3	5.0	2.3	5.0	2.3	5.0	2.3
LO2 Antigeysering	45%	5.0	2.3	5.0	2.3	5.0	2.3	5.0	2.3	5.0	2.3	5.0	2.3	5.0	2.3
GSE Purge System	10%	10.0	1.0	10.0	1.0	10.0	1.0	10.0	1.0	10.0	1.0	10.0	1.0	10.0	1.0
Nitrogen Purge	-														
Total Wt'd Score	100%		5.5		5.5		5.5		5.5		5.5		5.5		5.5
Ranking			1		1		1		1		1		1		1

Configuration		2B-1-OTF5	
Selection Criteria	Wt	Score	Wt'd
LH2 Recirculation	45%	10.0	4.5
LO2 Antigeysering	45%	5.0	2.3
GSE Purge System	10%	10.0	1.0
Nitrogen Purge	-		
Total Wt'd Score	100%		7.8
Ranking			6

Options 1 and 2B Ranked Best For No Additional Disconnects Required For On Pad Operations



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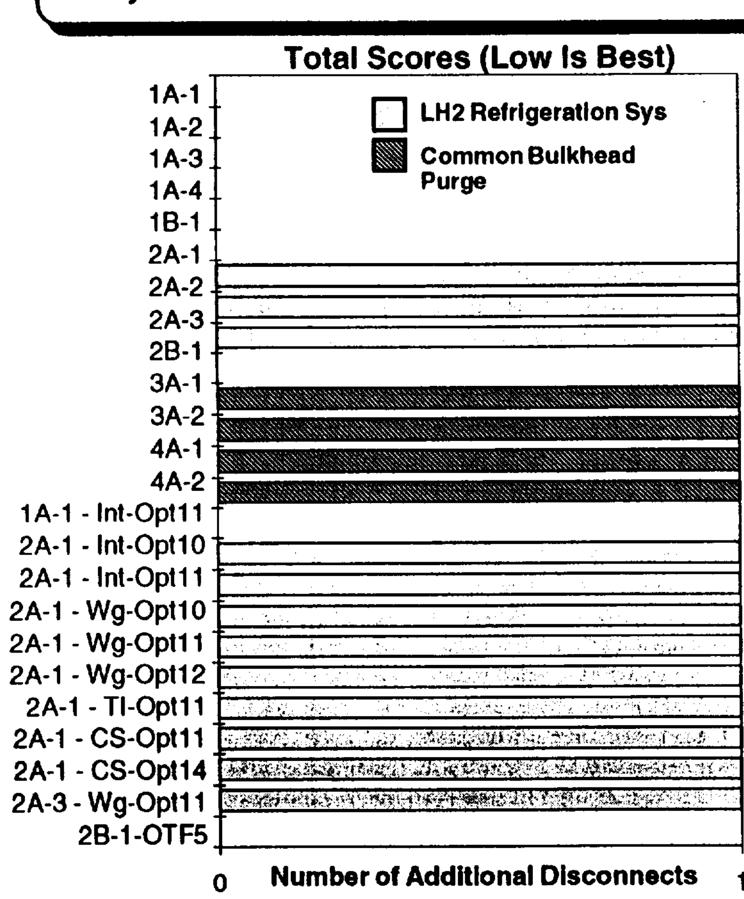
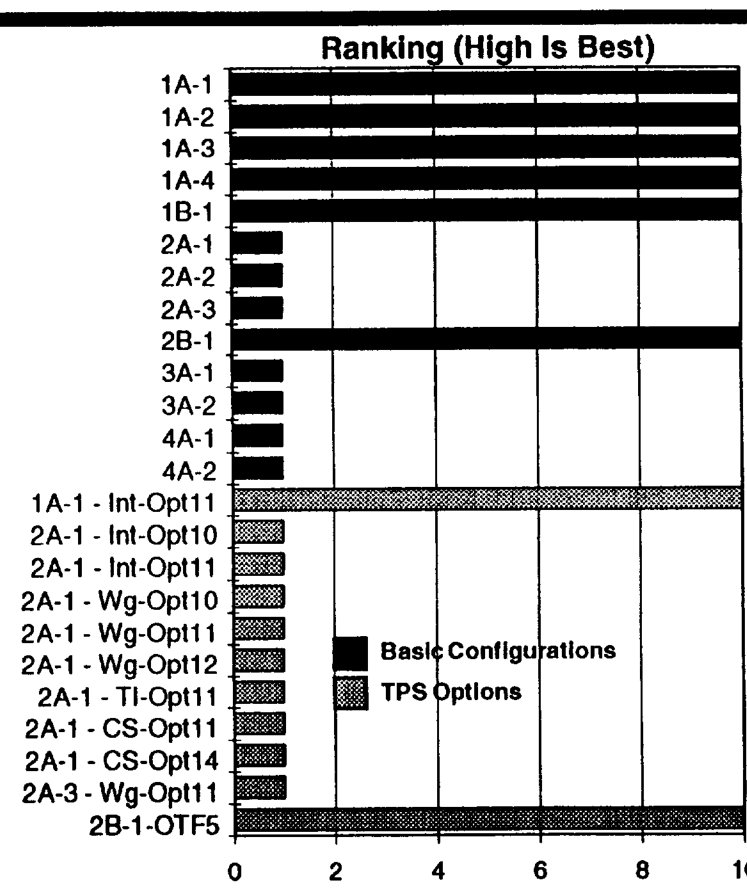
6c. Systems requiring disconnect - (Quantitative evaluation) - The candidate vehicle options are compared on the basis of additional disconnects necessary to permit vehicle launch. The scoring will include a complexity factor applied to the additional disconnects. A purging system disconnect for frost avoidance is an example of such a system.





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System Requiring Disconnect

Major Systems	
LO2 Loading	Not a discriminator
LH2 Loading	Not a discriminator
RP1 Loading	Not a discriminator
Nitrogen Purge	Not a discriminator
Propellant Loading, Storage and Transfer System (LH2, LO2, RP-1)	Not a discriminator
Prelaunch engine purge system (Heated GN2)	Not a discriminator
Post Scrub/Abort engine purge system (GN2 and Helium)	Not a discriminator
Helium supply system for engine purges & valve activation	Not a discriminator
Hazardous Gas Detection System	Not a discriminator
Helium purge system to inert possible lea sources & prevent icing at ground propellant fill and bleed disconnects	Not a discriminator
Propellant tank purge, stand by pressurization and pre-flight pressurization panels	Not a discriminator
LH2 Refrigeration	Discriminator
LO2 Anti-Geysering	Not A Discriminator
GSE Purge System	Discriminator

Based on number of systems only.
Because disconnect is automatic, no one disconnect poses more operational activities than another

Complexity	
LH2 Recirculation	50%
GSE Purge System	50%

Sys. Requiring Disconnect

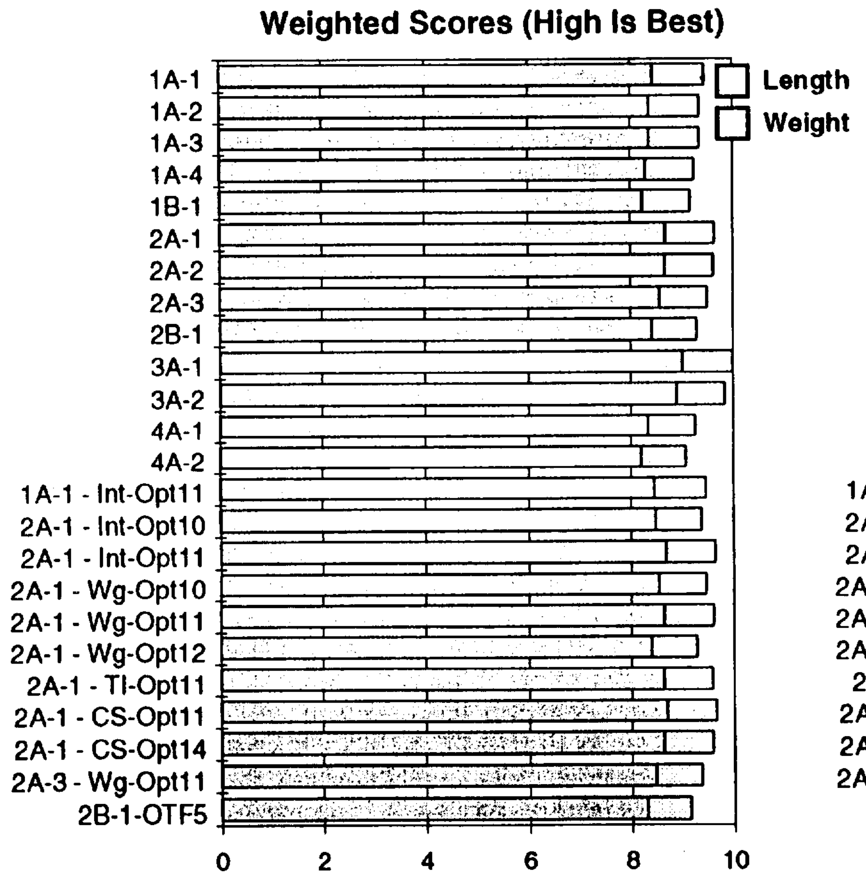
Configuration		1A-1		1A-2		1A-3		1A-4		1B-1		2A-1		2A-2		2A-3		2B-1	
Selection Criteria	Wt	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
LH2 Refrigeration	50%	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	1.0	0.5	1.0	0.5	1.0	0.5	10.0	5.0
GSE Purge System	50%	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0
Total Wt'd Score	100%		10.0		10.0		10.0		10.0		10.0		5.5		5.5		5.5		10.0

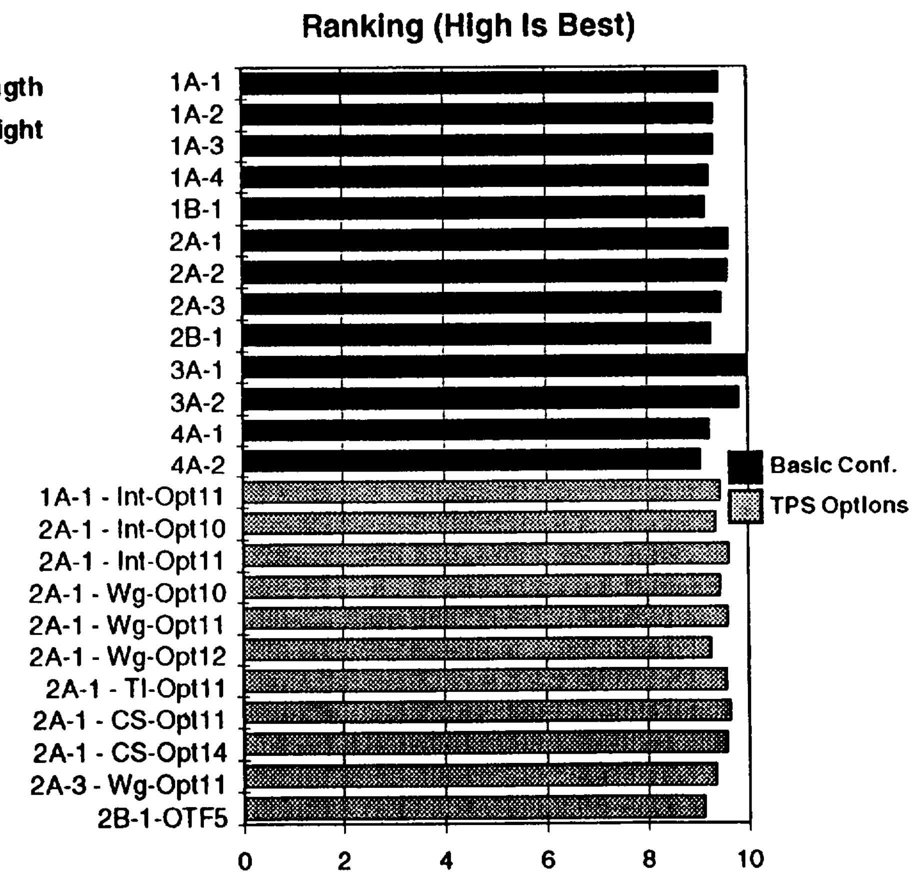
Configuration		3A-1		3A-2		3A-3		4A-1		4A-2		1A-1 - Int-Opt11		2A-1 - Int-Opt10		2A-1 - Int-Opt11		2A-1 - W
Selection Criteria	Wt	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score
LH2 Refrigeration	50%	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	1.0	0.5	1.0	0.5	1.0
GSE Purge System	50%	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	10.0	5.0	10.0	5.0	10.0	5.0	10.0
Total Wt'd Score	100%		5.5		5.5		5.5		5.5		5.5		10.0		5.5		5.5	

Configuration		g-Opt10	2A-1 - Wg-Opt11		2A-1 - Wg-Opt12		2A-1 - Tl-Opt11		2A-1 - CS-Opt11		2A-1 - CS-Opt14		2A-3 - Wg-Opt11		2B-1-OTF5	
Selection Criteria	Wt	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
LH2 Refrigeration	50%	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	10.0	5.0
GSE Purge System	50%	5.0	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0	10.0	5.0
Total Wt'd Score	100%	5.5		5.5		5.5		5.5		5.5		5.5		5.5		10.0

Option 3A-1 Ranked Best - Smallest Vehicle Size And Weight Leads To Smallest Facilities

6d. Facilities (Qualitative evaluation) - The candidate vehicle options are compared according to the number of additional on-pad facilities and height of such facilities and other differences that may be surface during the study.





NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Facilities - Pad

Clean Pad - Required Facilities

Propellant Storage/Loading	Same amount propellant required for all configurations - Not a discriminator
Lightning protection	Required for all configurations - Not a discriminator
Tower	Access at pad only available to aft area of vehicle from launch deck Access for passengers available from mobile GSE covered in unique GSE section Not a discriminator
Erector	In-place erector at pad - DISCRIMINATOR

Erector
Ranking based on Vehicle Height

Configuration		1A-1		1A-2		1A-3		1A-4		1B-1		2A-1		2A-2	
Selection Criteria	**Wt**	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
Height	90%	9.4	8.4	9.3	8.4	9.3	8.4	9.2	8.3	9.1	8.2	9.6	8.7	9.6	8.7
Weight	10%	10.0	1.0	9.7	1.0	9.7	1.0	9.4	0.9	9.2	0.9	9.6	1.0	9.5	1.0
Total	100%		9.4		9.3		9.3		9.2		9.2		9.6		9.6

Configuration		2A-3		2B-1		3A-1		3A-2		3A-3		4A-1		4A-2	
Selection Criteria	**Wt**	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
Height	90%	9.5	8.6	9.3	8.4	10.0	9.0	9.9	8.9	10.0	9.0	9.3	8.3	9.1	8.2
Weight	10%	9.2	0.9	8.7	0.9	9.8	1.0	9.4	0.9	9.7	1.0	9.1	0.9	8.7	0.9
Total	100%		9.5		9.3		10.0		9.8		9.9		9.2		9.1

Configuration		1A-1 - Int-Opt11		2A-1 - Int-Opt10		2A-1 - Int-Opt11		2A-1 - Wg-Opt10		2A-1 - Wg-Opt11		2A-1 - Wg-Opt12		2A-1 - Tl-Opt11	
Selection Criteria	**Wt**	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
Height	90%	9.4	8.5	9.4	8.5	9.6	8.7	9.5	8.5	9.6	8.6	9.3	8.4	9.6	8.6
Weight	10%	10.0	1.0	8.9	0.9	9.6	1.0	9.1	0.9	9.5	0.9	8.7	0.9	9.4	0.9
Total	100%		9.5		9.4		9.6		9.4		9.6		9.3		9.6

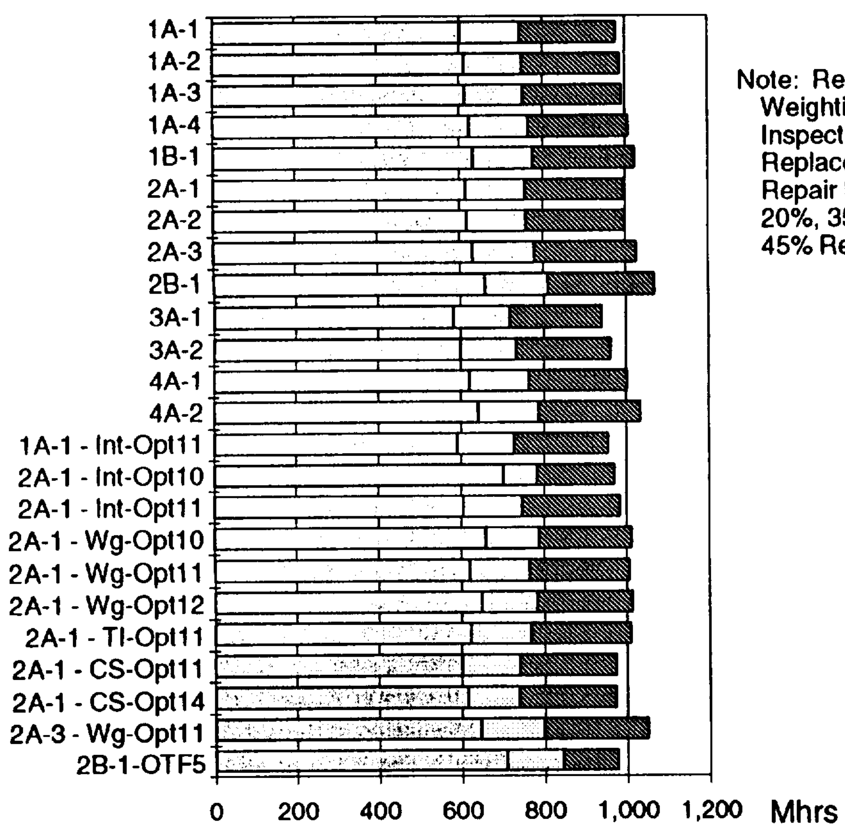
Configuration		2A-1 - CS-Opt11		2A-1 - CS-Opt14		2A-3 - Wg-Opt11		2B-1-OTF5	
Selection Criteria	**Wt**	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
Height	90%	9.7	8.7	9.6	8.6	9.4	8.5	9.2	8.3
Weight	10%	9.6	1.0	9.4	0.9	8.9	0.9	8.3	0.8
Total	100%		9.6		9.6		9.4		9.1

Option 2A-1 Intertank Option 10 Ranks Best For Lowest Inspection, Replacement & Repair Hours

SSTO

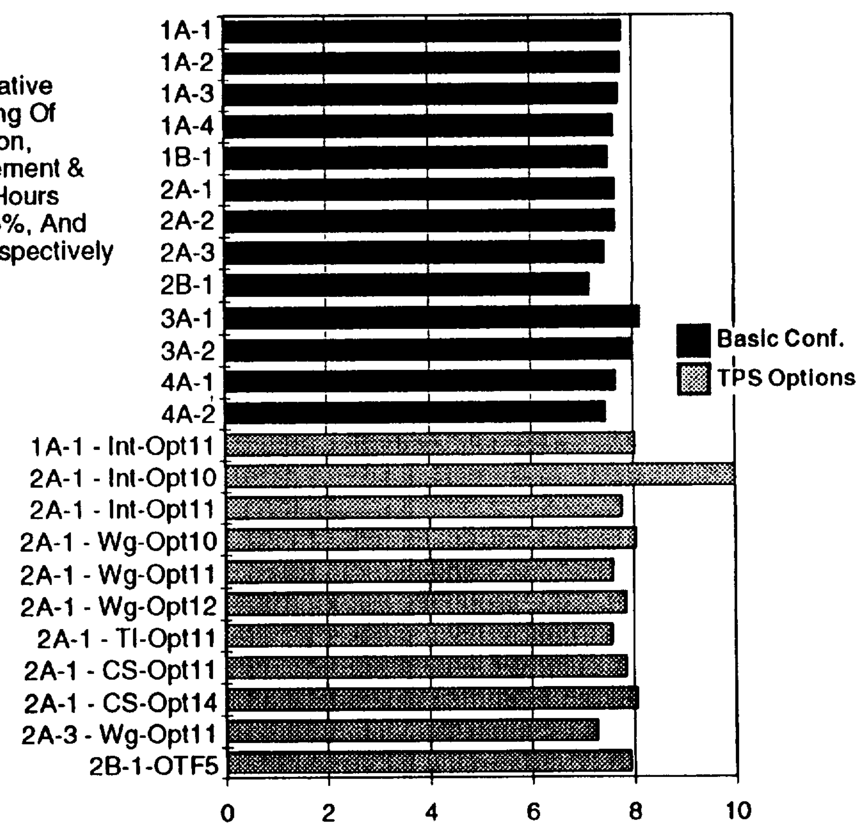
7a. Wide area coverage - (Quantitative Analysis) - The candidate vehicle options are compared based on the wide area coverage (square footage) that will have to be inspected, monitored, and maintained.

Inspection, Replacement, Repair Mhrs (Low Is Best)



Note: Relative Weighting Of Inspection, Replacement & Repair Hours 20%, 35%, And 45% Respectively

Ranking (High Is Best)



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Wide Coverage

Vehicle Data (Numbers In First 5 Rows Indicate Type Of TPS Attachment)

Configuration	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3	4A-1
LH Tank	1	2	1	2	7	1	2	1	7	1	2	2	1
LO Tank	8	8	8	8	8	8	8	8	8	8	8	8	8
Intertank & Other	9	9	9	9	9	9	9	9	9	9	9	9	9
Nose	9	9	9	9	9	9	9	9	9	9	9	9	9
Wing/Fin	9	9	9	9	9	9	9	9	9	9	9	9	9
Surface Area - All													
AETB - Fwd Fus	355	361	362	369	374	299	301	308	319	384	394	384	193
AETB - Wing/Elvn	1,468	1,494	1,496	1,523	1,544	1,502	1,508	1,543	1,598	1,479	1,518	1,479	1,548
AETB - BF/Stub*	1,175	1,196	1,198	1,219	1,236	1,203	1,208	1,236	1,280	1,184	1,215	1,184	1,240
AFRSI - Fwd Fus	303	308	309	314	319	237	238	244	253	307	315	307	639
AFRSI - LH Tank	2,941	2,993	2,998	3,051	3,094	3,352	3,365	3,444	3,732	4,773	4,898	4,773	4,188
AFRSI - Intertank	4,623	4,713	4,722	4,815	4,889	4,684	4,705	4,826	5,016	1,825	1,886	1,825	4,215
AFRSI - LO Tank	1,562	1,589	1,592	1,620	1,643	1,769	1,777	1,818	1,883	1,489	1,528	1,489	986
AFRSI - Thrust Skirt	741	754	755	768	779	758	761	779	807	746	766	746	0
AFRSI - Thrust Cone	1,473	1,499	1,501	1,528	1,550	1,507	1,514	1,549	1,604	1,484	1,523	1,484	1,626
AFRSI - Wing/Elvn	2,089	2,126	2,130	2,168	2,198	2,138	2,147	2,197	2,275	2,105	2,160	2,105	2,204
AFRSI - Tail	1,749	1,780	1,783	1,814	1,840	1,790	1,797	1,839	1,905	2,052	2,106	2,052	1,846
AFRSI - BF/Stub	569	579	580	591	599	583	585	599	620	574	589	574	601
TABI - Fwd Fus	561	571	572	582	590	413	414	424	439	540	554	540	970
TABI - LH Tank	2,131	2,169	2,172	2,211	2,242	1,433	1,439	1,472	1,598	2,389	2,452	2,389	3,036
TABI - Intertank	2,560	2,605	2,609	2,655	2,693	2,593	2,603	2,664	2,759	1,679	1,723	1,679	2,022
TABI - LO Tank	669	680	682	694	703	1,278	1,283	1,313	1,360	747	767	747	496
TABI - Wing/Elvn	851	866	868	883	896	871	875	895	927	858	880	858	898
TABI - Tail	0	0	0	0	0	0	0	0	0	384	394	384	0
CSIC - LH Tank	0	0	0	0	0	0	0	0	0	0	0	0	0
CSIC - Intertank	0	0	0	0	0	0	0	0	0	0	0	0	0
CSIC - Wing/Elvn	0	0	0	0	0	0	0	0	0	0	0	0	0

* Payload Canister Is Processed Offline. Inspection, repair, and replacement for AFRSI on the canister is not included in this part of the analysis

Vehicle Data (Number

Configuration	4A-2	1A-1 - Int-Opt11	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - Tl-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
LH Tank	2	1	1	1	1	1	1	1	1	1	1	7
LO Tank	8	8	8	8	8	8	8	8	8	8	8	8
Intertank & Other	9	11	10	11	9	9	9	9	9	9	9	9
Nose	9	9	9	9	9	9	9	9	9	9	9	9
Wing/Fin	9	9	9	9	10	11	12	11	11	14	11	9
Surface Area - All												
AETB - Fwd Fus	199	354	314	300	309	302	320	303	299	303	315	328
AETB - Wing/Elvn	1,601	1,464	1,576	1,505	1,553	1,514	1,605	1,519	1,498	1,519	1,578	1,644
AETB - BF/Stub*	1,282	1,172	1,262	1,205	1,243	1,212	1,285	1,216	1,200	1,216	1,264	1,317
AFRSI - Fwd Fus	661	302	249	238	245	239	254	240	237	240	249	260
AFRSI - LH Tank	4,329	2,934	3,517	3,357	3,464	3,378	3,580	3,390	3,343	3,390	3,522	0
AFRSI - Intertank	4,375	4,225	0	4,296	4,858	4,724	5,037	4,743	4,670	4,743	4,947	5,174
AFRSI - LO Tank	1,020	1,558	1,857	1,772	1,829	1,783	1,890	1,789	1,765	1,789	1,859	1,937
AFRSI - Thrust Skirt	0	739	795	759	783	764	810	767	756	767	796	830
AFRSI - Thrust Cone	1,681	1,469	1,582	1,510	1,558	1,519	1,610	1,525	1,503	1,525	1,584	1,650
AFRSI - Wing/Elvn	2,279	2,084	2,244	2,142	337	2,155	348	2,162	1,599	1,622	2,247	2,341
AFRSI - Tail	1,908	1,745	1,878	1,793	1,850	1,804	1,912	1,810	1,785	1,810	1,881	1,959
AFRSI - BF/Stub	621	568	611	584	602	587	622	589	581	589	612	638
TABI - Fwd Fus	1,003	560	433	413	427	416	441	417	412	417	434	452
TABI - LH Tank	3,139	2,126	1,503	1,435	1,481	1,444	1,530	1,449	1,429	1,449	1,505	0
TABI - Intertank	2,091	2,553	0	2,597	2,680	2,613	2,770	2,622	2,586	2,622	2,724	2,838
TABI - LO Tank	513	667	1,341	1,280	1,320	1,287	1,365	1,292	1,274	1,292	1,342	1,398
TABI - Wing/Elvn	929	849	914	873	0	878	0	881	869	341	916	954
TABI - Tail	0	0	0	0	0	0	0	0	0	0	0	0
CSIC - LH Tank	0	0	0	0	0	0	0	0	0	0	0	4,915
CSIC - Intertank	0	0	7,309	0	0	0	0	0	0	0	0	0
CSIC - Wing/Elvn	0	0	0	0	2,774	0	1,839	0	0	541	0	0

* Payload Canister Is Proce

Inspection

	Factor	Reduction	
AFRSI	0.0223	50%	(1/Shuttle AFRSI Area * Shuttle AFRSI Hours*(1-Red))
TABI	0.0223	50%	(1/Shuttle AFRSI Area * Shuttle AFRSI Hours*(1-Red))
AETB	0.0310	50%	(1/Shuttle HRSI Area * Shuttle HRSI Hours*(1-Red))
CSIc	0.0310	50%	(1/Shuttle HRSI Area * Shuttle HRSI Hours*(1-Red))

Configuration	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3	4A-1
AETB - Fwd Fus	11	11	11	11	12	9	9	10	10	12	12	12	6
AETB - Wing/Elvn	46	46	46	47	48	47	47	48	50	46	47	46	48
AETB - BF/Stub*	36	37	37	38	38	37	37	38	40	37	38	37	38
AFRSI - Fwd Fus	7	7	7	7	7	5	5	5	6	7	7	7	14
AFRSI - LH Tank	66	67	67	68	69	75	75	77	83	106	109	106	93
AFRSI - Intertank	103	105	105	107	109	104	105	108	112	41	42	41	94
AFRSI - LO Tank	35	35	35	36	37	39	40	41	42	33	34	33	22
AFRSI - Thrust Skirt	17	17	17	17	17	17	17	17	18	17	17	17	0
AFRSI - Thrust Cone	33	33	33	34	35	34	34	35	36	33	34	33	36
AFRSI - Wing/Elvn	47	47	47	48	49	48	48	49	51	47	48	47	49
AFRSI - Tail	39	40	40	40	41	40	40	41	42	46	47	46	41
AFRSI - BF/Stub	13	13	13	13	13	13	13	13	14	13	13	13	13
TABI - Fwd Fus	12	13	13	13	13	9	9	9	10	12	12	12	22
TABI - LH Tank	47	48	48	49	50	32	32	33	36	53	55	53	68
TABI - Intertank	57	58	58	59	60	58	58	59	61	37	38	37	45
TABI - LO Tank	15	15	15	15	16	28	29	29	30	17	17	17	11
TABI - Wing/Elvn	19	19	19	20	20	19	19	20	21	19	20	19	20
TABI - Tail	0	0	0	0	0	0	0	0	0	9	9	9	0
CSIC - LH Tank	0	0	0	0	0	0	0	0	0	0	0	0	0
CSIC - Intertank	0	0	0	0	0	0	0	0	0	0	0	0	0
CSIC - Wing/Elvn	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Inspection Hrs	601.4	612.2	613.2	624.4	633.3	614.6	617.2	631.8	660.1	583.5	599.2	583.5	621.1

Wide Coverage

Inspection

	Reduction		
AFRSI	50%	(1/Shuttle AFRSI Area * Shuttle AFRSI Hours*(1-Red))	TF
TABI	50%	(1/Shuttle AFRSI Area * Shuttle AFRSI Hours*(1-Red))	
AETB	50%	(1/Shuttle HRSI Area * Shuttle HRSI Hours*(1-Red))	
CSic	50%	(1/Shuttle HRSI Area * Shuttle HRSI Hours*(1-Red))	

Configuration	4A-2	1A-1 - Int-Opt11	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - Tl-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
AETB - Fwd Fus	6	11	10	9	10	9	10	9	9	9	10	10
AETB - Wing/Elvn	50	45	49	47	48	47	50	47	46	47	49	51
AETB - BF/Stub*	40	36	39	37	39	38	40	38	37	38	39	41
AFRSI - Fwd Fus	15	7	6	5	5	5	6	5	5	5	6	6
AFRSI - LH Tank	96	65	78	75	77	75	80	76	74	76	78	0
AFRSI - Intertank	97	94	0	96	108	105	112	106	104	106	110	115
AFRSI - LO Tank	23	35	41	39	41	40	42	40	39	40	41	43
AFRSI - Thrust Skirt	0	16	18	17	17	17	18	17	17	17	18	18
AFRSI - Thrust Cone	37	33	35	34	35	34	36	34	33	34	35	37
AFRSI - Wing/Elvn	51	46	50	48	8	48	8	48	36	36	50	52
AFRSI - Tail	43	39	42	40	41	40	43	40	40	40	42	44
AFRSI - BF/Stub	14	13	14	13	13	13	14	13	13	13	14	14
TABI - Fwd Fus	22	12	10	9	10	9	10	9	9	9	10	10
TABI - LH Tank	70	47	33	32	33	32	34	32	32	32	34	0
TABI - Intertank	47	57	0	58	60	58	62	58	58	58	61	63
TABI - LO Tank	11	15	30	29	29	29	30	29	28	29	30	31
TABI - Wing/Elvn	21	19	20	19	0	20	0	20	19	8	20	21
TABI - Tail	0	0	0	0	0	0	0	0	0	0	0	0
CSIC - LH Tank	0	0	0	0	0	0	0	0	0	0	0	152
CSIC - Intertank	0	0	227	0	0	0	0	0	0	0	0	0
CSIC - Wing/Elvn	0	0	0	0	86	0	57	0	0	17	0	0
Total Inspection Hrs	642.4	591.3	701.5	606.8	659.9	619.4	650.5	621.7	601.1	614.4	646.4	709.6

Replacement

	AFRSI		TABI		AETB		Csic	
Option	**Mhr**	**Serial**	**Mhr**	**Serial**	**Mhr**	**Serial**	**Mhr**	**Serial**
1	30.7	52.2	30.7	52.2				
2	28.2	46.7	28.2	46.7				
5							6.1	14.1
7	28.2	46.7	28.2	46.7				
8	30.7	52.2	30.7	52.2				
9	28.2	46.7	28.2	46.7	18.9	30.4		
10							6.1	14.1
11	28.2	46.7	28.2	46.7	18.9	30.4		
12							6.1	14.1
13	28.2	46.7	28.2	46.7				
14							6.1	14.1

Replacement Frequency	Factor	Shuttle Rplmnts	Shuttle Area	Dura-bility	Rain Impact	Rain Prob.
AFRSI	0.000248	9	3636	0.100	1.0	10%
TABI	0.000124	9	3636	0.050	1.0	10%
AETB	0.000087	6.67	844	0.010	2.0	10%
Csic	0.000071	6.67	844	0.010	0	10%

AFRSI Factor Formula = (1/Shuttle AFRSI Area) * # Shuttle Replcmts * Durability*(Rain Impact*%Prob. +No Rain Impact*(1-% Prob.)
TABI Factor Formula = (1/Shuttle AFRSI Area) * # Shuttle Replcmts * Durability*(Rain Impact*%Prob. +No Rain Impact*(1-% Prob.)
AETB Factor Formula = (1/Shuttle HRSI Area) * # Shuttle Replcmts* Durability*(Rain Impact*%Prob. +No Rain Impact*(1-% Prob.)
Csic Factor Formula = (1/Shuttle HRSI Area) * # Shuttle Replcmts* Durability*(Rain Impact*%Prob. +No Rain Impact*(1-% Prob.)

Wide Coverage

# of Replacements

Configuration	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3	4A-1
# OF REPLACEMENTS													
AETB - Fwd Fus	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
AETB - Wing/Elvn	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.13	0.13	0.13	0.13
AETB - BF/Stub*	0.10	0.10	0.10	0.11	0.11	0.10	0.10	0.11	0.11	0.10	0.11	0.10	0.11
AFRSI - Fwd Fus	0.07	0.08	0.08	0.08	0.08	0.06	0.06	0.06	0.06	0.08	0.08	0.08	0.16
AFRSI - LH Tank	0.73	0.74	0.74	0.76	0.77	0.83	0.83	0.85	0.92	1.18	1.21	1.18	1.04
AFRSI - Intertank	1.14	1.17	1.17	1.19	1.21	1.16	1.16	1.19	1.24	0.45	0.47	0.45	1.04
AFRSI - LO Tank	0.39	0.39	0.39	0.40	0.41	0.44	0.44	0.45	0.47	0.37	0.38	0.37	0.24
AFRSI - Thrust Skirt	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.20	0.18	0.19	0.18	0.00
AFRSI - Thrust Cone	0.36	0.37	0.37	0.38	0.38	0.37	0.37	0.38	0.40	0.37	0.38	0.37	0.40
AFRSI - Wing/Elvn	0.52	0.53	0.53	0.54	0.54	0.53	0.53	0.54	0.56	0.52	0.53	0.52	0.55
AFRSI - Tail	0.43	0.44	0.44	0.45	0.46	0.44	0.44	0.46	0.47	0.51	0.52	0.51	0.46
AFRSI - BF/Stub	0.14	0.14	0.14	0.15	0.15	0.14	0.14	0.15	0.15	0.14	0.15	0.14	0.15
TABI - Fwd Fus	0.07	0.07	0.07	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.07	0.12
TABI - LH Tank	0.26	0.27	0.27	0.27	0.28	0.18	0.18	0.18	0.20	0.30	0.30	0.30	0.38
TABI - Intertank	0.32	0.32	0.32	0.33	0.33	0.32	0.32	0.33	0.34	0.21	0.21	0.21	0.25
TABI - LO Tank	0.08	0.08	0.08	0.09	0.09	0.16	0.16	0.16	0.17	0.09	0.09	0.09	0.06
TABI - Wing/Elvn	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
TABI - Tail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.00
CSIC - LH Tank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CSIC - Intertank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CSIC - Wing/Elvn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Replacements	5.07	5.16	5.17	5.27	5.34	5.24	5.26	5.39	5.63	4.88	5.01	4.88	5.21

# of Replacements

Configuration	4A-2	1A-1 - Int-Opt11	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - Tl-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
# OF REPLACEMENTS												
AETB - Fwd Fus	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
AETB - Wing/Elvn	0.14	0.13	0.14	0.13	0.13	0.13	0.14	0.13	0.13	0.13	0.14	0.14
AETB - BF/Stub*	0.11	0.10	0.11	0.10	0.11	0.11	0.11	0.11	0.10	0.11	0.11	0.11
AFRSI - Fwd Fus	0.16	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
AFRSI - LH Tank	1.07	0.73	0.87	0.83	0.86	0.84	0.89	0.84	0.83	0.84	0.87	0.00
AFRSI - Intertank	1.08	1.05	0.00	1.06	1.20	1.17	1.25	1.17	1.16	1.17	1.22	1.28
AFRSI - LO Tank	0.25	0.39	0.46	0.44	0.45	0.44	0.47	0.44	0.44	0.44	0.46	0.48
AFRSI - Thrust Skirt	0.00	0.18	0.20	0.19	0.19	0.19	0.20	0.19	0.19	0.19	0.20	0.21
AFRSI - Thrust Cone	0.42	0.36	0.39	0.37	0.39	0.38	0.40	0.38	0.37	0.38	0.39	0.41
AFRSI - Wing/Elvn	0.56	0.52	0.56	0.53	0.08	0.53	0.09	0.54	0.40	0.40	0.56	0.58
AFRSI - Tail	0.47	0.43	0.46	0.44	0.46	0.45	0.47	0.45	0.44	0.45	0.47	0.48
AFRSI - BF/Stub	0.15	0.14	0.15	0.14	0.15	0.15	0.15	0.15	0.14	0.15	0.15	0.16
TABI - Fwd Fus	0.12	0.07	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06
TABI - LH Tank	0.39	0.26	0.19	0.18	0.18	0.18	0.19	0.18	0.18	0.18	0.19	0.00
TABI - Intertank	0.26	0.32	0.00	0.32	0.33	0.32	0.34	0.32	0.32	0.32	0.34	0.35
TABI - LO Tank	0.06	0.08	0.17	0.16	0.16	0.16	0.17	0.16	0.16	0.16	0.17	0.17
TABI - Wing/Elvn	0.11	0.11	0.11	0.11	0.00	0.11	0.00	0.11	0.11	0.04	0.11	0.12
TABI - Tail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CSIC - LH Tank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35
CSIC - Intertank	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CSIC - Wing/Elvn	0.00	0.00	0.00	0.00	0.20	0.00	0.13	0.00	0.00	0.04	0.00	0.00
Total Replacements	5.39	4.96	4.46	5.15	5.04	5.28	5.14	5.30	5.09	5.14	5.51	4.99

Wide Coverage

Configuration	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3	4A-1
AETB - Fwd Fus	1	1	1	1	1	0	0	1	1	1	1	1	0
AETB - Wing/Elvn	2	2	2	3	3	2	2	3	3	2	2	2	3
AETB - BF/Stub*	2	2	2	2	2	2	2	2	2	2	2	2	2
AFRSI - Fwd Fus	2	2	2	2	2	2	2	2	2	2	2	2	4
AFRSI - LH Tank	22	21	23	21	22	25	23	26	26	36	34	33	32
AFRSI - Intertank	32	33	33	34	34	33	33	34	35	13	13	13	29
AFRSI - LO Tank	12	12	12	12	12	13	14	14	14	11	12	11	7
AFRSI - Thrust Skirt	5	5	5	5	5	5	5	5	6	5	5	5	0
AFRSI - Thrust Cone	10	10	10	11	11	11	11	11	11	10	11	10	11
AFRSI - Wing/Elvn	15	15	15	15	15	15	15	15	16	15	15	15	15
AFRSI - Tail	12	8	8	8	9	8	8	9	9	10	10	10	9
AFRSI - BF/Stub	4	3	3	3	3	3	3	3	3	3	3	3	3
TABI - Fwd Fus	2	2	2	2	2	1	1	1	2	2	2	2	3
TABI - LH Tank	8	8	8	8	8	5	5	6	6	9	9	8	12
TABI - Intertank	9	9	9	9	9	9	9	9	10	6	6	6	7
TABI - LO Tank	3	3	3	3	3	5	5	5	5	3	3	3	2
TABI - Wing/Elvn	3	3	3	3	3	3	3	3	3	3	3	3	3
TABI - Tail	0	0	0	0	0	0	0	0	0	1	1	1	0
CSIC - LH Tank	0	0	0	0	0	0	0	0	0	0	0	0	0
CSIC - Intertank	0	0	0	0	0	0	0	0	0	0	0	0	0
CSIC - Wing/Elvn	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Mhrs	144.2	138.9	141.7	141.7	143.7	143.9	141.9	147.9	152.0	134.0	133.8	130.3	143.3

Configuration	4A-2	1A-1 - Int-Opt11	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - Tl-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
AETB - Fwd Fus	0	1	0	0	1	0	1	0	0	0	1	1
AETB - Wing/Elvn	3	2	3	2	0	2	0	2	2	0	3	3
AETB - BF/Stub*	2	2	0	2	2	2	2	2	2	2	2	2
AFRSI - Fwd Fus	5	2	0	2	2	2	2	2	2	2	2	2
AFRSI - LH Tank	30	22	27	26	26	26	27	26	25	26	27	0
AFRSI - Intertank	31	29	0	30	34	33	35	33	33	33	35	36
AFRSI - LO Tank	8	12	14	13	14	14	14	14	13	14	14	15
AFRSI - Thrust Skirt	0	5	0	5	5	5	6	5	5	5	6	6
AFRSI - Thrust Cone	12	10	0	11	11	11	11	11	10	11	11	12
AFRSI - Wing/Elvn	16	15	16	15	0	15	0	15	11	0	16	16
AFRSI - Tail	9	8	9	8	9	8	9	8	8	8	9	9
AFRSI - BF/Stub	3	3	0	3	3	3	3	3	3	3	3	3
TABI - Fwd Fus	3	2	0	1	1	1	2	1	1	1	2	2
TABI - LH Tank	11	8	6	5	6	5	6	6	5	6	6	0
TABI - Intertank	7	9	0	9	9	9	10	9	9	9	10	10
TABI - LO Tank	2	3	5	5	5	5	5	5	5	5	5	5
TABI - Wing/Elvn	3	3	3	3	0	3	0	3	3	0	3	3
TABI - Tail	0	0	0	0	0	0	0	0	0	0	0	0
CSIC - LH Tank	0	0	0	0	0	0	0	0	0	0	0	10
CSIC - Intertank	0	0	0	0	0	0	0	0	0	0	0	0
CSIC - Wing/Elvn	0	0	0	0	0	0	0	0	0	0	0	0
Total Mhrs	144.6	135.9	81.9	141.3	127.7	145.0	132.1	145.5	139.8	124.9	151.3	133.8

Repair

Typical Tile Repair Hours For Shuttle 835 Hours
Typical Blanket Repair Hours For Shuttle 373 Hours

Repair	Factor	Shuttle Repair Hours	Shuttle Area	Dura-bility	Rain Impact	Rain Prob.
AFRSI	0.010259	373	3636	0.100	1.0	10%
TABI	0.005129	373	3636	0.050	1.0	10%
AETB	0.010883	835	844	0.010	2.0	10%

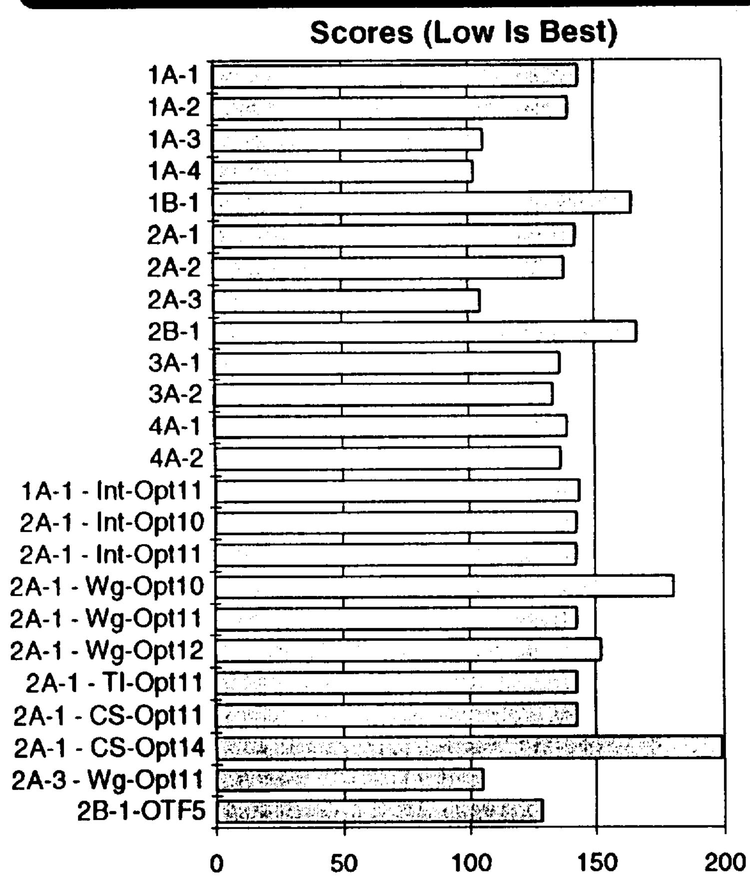
AFRSI Repair Factor = (1/Shuttle AFRSI Area) * Shuttle Repair Hrs * Durability*(Rain Impact*%Prob. +No Rain Impact*(1-% P
TABI Repair Factor = (1/Shuttle AFRSI Area) * Shuttle Repair Hrs * Durability*(Rain Impact*%Prob. +No Rain Impact*(1-% P
AETB Repair Factor = (1/Shuttle HRSI Area) * Shuttle Repair Hrs* Durability*(Rain Impact*%Prob. +No Rain Impact*(1-% Pro
Note: Csic Panels replaced only, not repaired

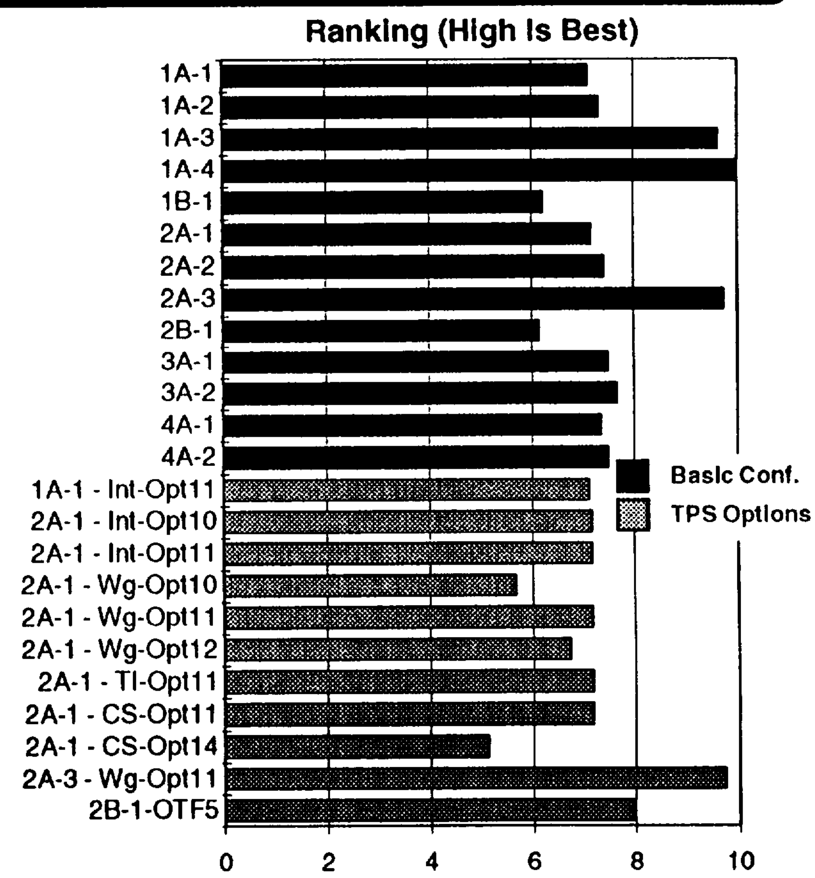
Configuration	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3	4A-1	4A-2	1A-1 - Int-Opt11	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - TI-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
AETB - Fwd Fus	4	4	4	4	4	3	3	3	3	4	4	4	2	2	4	3	3	3	3	3	3	3	3	3	4
AETB - Wing/Elvn	16	16	16	17	17	16	16	17	17	16	17	16	17	17	16	17	16	17	16	17	17	18	17	17	18
AETB - BF/Stub*	13	13	13	13	13	13	13	13	14	13	13	13	13	14	13	14	13	14	13	14	13	13	13	14	14
AFRSI - Fwd Fus	3	3	3	3	3	2	2	3	3	3	3	3	7	7	3	3	2	3	2	3	2	2	2	3	3
AFRSI - LH Tank	30	31	31	31	32	34	35	35	38	49	50	49	43	44	30	36	34	36	35	37	35	34	35	36	
AFRSI - Intertank	47	48	48	49	50	48	48	50	51	19	19	19	43	45	43	0	44	50	48	52	49	48	49	51	53
AFRSI - LO Tank	16	16	16	17	17	18	18	19	19	15	16	15	10	10	16	19	18	19	18	19	18	18	18	19	20
AFRSI - Thrust Skirt	8	8	8	8	8	8	8	8	8	8	8	8			8	8	8	8	8	8	8	8	8	8	9
AFRSI - Thrust Cone	15	15	15	16	16	15	16	16	16	15	16	15	17	17	15	16	15	16	16	17	16	15	16	16	17
AFRSI - Wing/Elvn	21	22	22	22	23	22	22	23	23	22	22	22	23	23	21	23	22	3	22	4	22	16	17	23	24
AFRSI - Tail	18	18	18	19	19	18	18	19	20	21	22	21	19	20	18	19	18	19	19	20	19	18	19	19	20
AFRSI - BF/Stub	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	7
TABI - Fwd Fus	3	3	3	3	3	2	2	2	2	3	3	3	5	5	3	2	2	2	2	2	2	2	2	2	2
TABI - LH Tank	11	11	11	11	11	7	7	8	8	12	13	12	16	16	11	8	7	8	7	8	7	7	7	8	
TABI - Intertank	13	13	13	14	14	13	13	14	14	9	9	9	10	11	13		13	14	13	14	13	13	13	14	15
TABI - LO Tank	3	3	3	4	4	7	7	7	7	4	4	4	3	3	3	7	7	7	7	7	7	7	7	7	7
TABI - Wing/Elvn	4	4	4	5	5	4	4	5	5	4	5	4	5	5	4	5	4		5		5	4	2	5	5
TABI - Tail										2	2	2													
CSIC - LH Tank																									
CSIC - Intertank																									
CSIC - Wing/Elvn																									
Total Repair Hrs	232	236	237	241	244	239	240	246	257	225	231	225	238	246	227	186	235	223	241	231	242	233	233	251	216

Options 1A-3, -4, 2A-3, And 2A-3 Wg-Opt11 Ranked Best For Localized Area Coverage

SSTO

7b. Localized area coverage - (Quantitative Analysis) - The candidate vehicle options are compared based on the complexity of local area coverage requirements (critical joints; localized high stress areas) within the each of the candidate vehicles.





NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

MAINTENANCE OPERATIONS-Localized Area Coverage

The candidate vehicle options are compared based on the complexity of local area coverage requirements (critical joints; localized high stress areas) within each of the candidate vehicles. The critical joints are assessed on the number of wing and RP tank attachment points. Other structures, such as nose areas, control surfaces and thrust structures are considered to have the same number of critical joints. The localized high stress areas are considered to be the tank splices. The degree that a localized high stress area has an effect on the vehicle selection is dependent on the designs critical features. These include critical features associated with stringer designs, non integral designs and materials.

In general, the maintenance operations -localized area coverage was based on several assumptions. These assumptions reflect the difficulties of inspection of the design configurations during the post-flight inspections as applied to design and materials selections. The following assumptions were made.

Number of fracture critical components

The level of inspection over the localized area coverage will not be consistent over the entire vehicle. Fracture critical items (i.e. tank splices, stringers and fittings) will require more intensive inspections and instrumentation than less critical components. Therefore, design configurations that have the largest number of fracture critical components will require the largest number of inspections.

Design Assumptions

Several design considerations effect the ability of the structure to be inspected. Primary design considerations include the complexity of the design, the surface area to be inspected, the number of fracture critical components and the number of components to be inspected and instrumented.

Complexity of design

Inherently, simple designs tend to be better suited to inspection and instrumentation than do complex designs. The more complex designs, such as skin and stringer designs have bends and protrusions that limit accessibility to hardware, inspection techniques, implementation and interpretation. It was also assumed that a more complex design may also require fabrication of specific tooling to facilitate inspection.

Number of fracture critical components

The level of inspection over the localized area coverage will not be consistent over the entire vehicle. Fracture critical items (i.e., tank splices, stringers and fittings) will require more intensive inspections and instrumentation than less critical components. Therefore, design configurations that have the largest number of fracture critical components will require the largest number of inspections and instrumentations.

Number of components inspected

Non integrated design configurations have a larger surface area, are more complex and have more critical components. These problems directly effect the NDI/IHM programs by increasing the number of inspection points and area to be inspected.

Materials Assumptions

Due to a lack of information on the composite/TPS structures, it was assumed that the IM7/977-2, AFR 700, Gr/BMI, TMC composite materials and Al-Li alloys have approximately same adaptability to NDI/IHM techniques. In general, the TPS materials assumed that the flexible blanket insulation is considered non inspectable by means other than visual inspection and the C/SiC is more readily adaptable to NDI/IHM.

Critical feature factors

The primary number of components was considered to be the number of skins and the number of TPS layers. The identification of a critical design or material in each of the vehicle structures was evaluated and assigned a critical feature factor. This factor reflects the effect the critical feature will have on the post flight inspections. It was generally considered that these variables would increase the difficulty of inspection by an order of magnitude for each critical factor.

The critical feature factor of stringer design evaluation as applied to post-flight inspections indicated that due to the tight bend radius would be difficult to evaluate using NDI techniques. Current laser based ultrasonics only allow for 30 degree angle from the inspection plane. This indicates that complex tooling would be required for inspection. This configuration has a greater number of critical points of interest. The bond lines and corners are stress concentration points that would require a concentrated level of inspection. A correction factor of 3.75 was applied to the stringer designs to compensate for these difficulties.

The critical feature factor of non intergral design evaluation as applied to post flight inspections indicated that these designs have multiple skins would effectively double the area for instrumentation. This design also increases the number of bond lines and adds a support structure for the internal tank that would increase the number of critical inspection points. A correction factor of 2.0 was applied to non integral designs to compensate for these difficulties.

The critical feature factor of designs that utilize ceramic composites (Blackglas) as applied to post flight inspections indicated that there has been limited application of NDI techniques applied to ceramic composites. This indicated that inspection of this material may require advanced techniques or development of techniques. A correction factor of 2.0 was applied to ceramic composite designs to compensate for these difficulties.

The critical feature factor of designs that utilize TABI or AFRSI blankets as applied to post flight inspections indicated that there has been limited application of NDI techniques applied to TABI or AFRSI blankets. This indicated that inspection of this material may require advanced techniques or development of techniques. It is also expected that if these techniques cannot be developed the blankets will require a complete visual inspection. A correction factor of 1.5 was applied to designs with TABI or AFRSI blankets to compensate for these difficulties.

The critical feature factor of designs that utilize TPS mechanical attachments, as applied to post flight inspections indicated that there may be additional difficulties associated with the design. The addition of mechanical attachment points and the associated gaps increases the amount of localized high stress areas. Inspection of this design may require advanced techniques or development of techniques. A correction factor of 2.0 was applied to designs with TPS mechanical attachments to compensate for these difficulties.

Trade study process

The trade study estimated the localized areas of coverage on each vehicle configuration by the tank splice areas. Double this area was multiplied by its critical feature factor to rate the effect this structure type has on the vehicles score. The sum of the structure localized areas of stress were recorded. The number of critical joints was estimated for each configuration (RP tank and wing attachments) and multiplied by the wing area as a rating of its effect on the vehicles' scores. It was estimated that each RP tank had two critical attach points based around the end circumferences of each tank. It was estimated that the wing attachments to LH2, aft skirt, thrust structure had 12 attachment points. All other attachment designs had 4. Since the critical areas make up the majority of the inspections, the high stressed areas were weighted heavier than the critical joints.

No. of skins + No. of TPS layers = Subtotal

Subtotal X Critical Feature Factor = Combined Critical Feature Factor

Table 1. Estimated High Stress Surface Areas of Tanks

Configuration	LH2 Tank Critical	LO2 Tank Critical	RP Tanks Critical	Wings
1A&B	614	422	2352	4705
2A&B	704	277	2352	4705
3	430	362	2164	4705
4	417	405	2352	4705

Table 2. Number of variables and applied critical feature factor

Trade option	No. of skins	No. of TPS layers	Sub Total	Design Critical Feature Factor	Critical Feature Factor
1	1	2	3	3.75	11.25
2	2	2	4	2.0	8
5	4	3	7	4.0	28
7	4	3	7	4.0	28
8	1	2	3	3.75	11.25
9	2	2	4	2.0	8
10	2	2	4	2.0	8.0
11	2	2	4	2.0	8
12	1	1	2	5.0	10
13	1	1	2	3.75	7.5
14	1	1	2	10.0	20

LOCATE.XLS

CONFIG	CRITICAL FEATURE FACTOR	LH2 CRITICAL AREA	CRITICAL FEATURE FACTOR	LO2 CRITICAL AREA	RP CRITICAL AREA	CRITICAL FEATURE FACTOR	WING AREA	WING ATTACH FACTOR	TOTALS	**RATING**
1A-1										
		1228		844	2351		4705	4705		
	11.25	13815	11.25	9495	26448.75	8	37640	56460	**143858.8**	**7.10612**
1A-2										
		1228		844	2351		4705	4705		
	8	9824	11.25	9495	26448.75	8	37640	56460	**139867.8**	**7.308886**
1A-3										
		1228		844	2351		4705	4705		
	11.25	13815	11.25	9495	26448.75	8	37640	18820	**106218.8**	**9.624266**
1A-4										
		1228		844	2351		4705	4705		
	8	9824	11.25	9495	26448.75	8	37640	18820	**102227.8**	**10**
1B-1										
		1228		844	2351		4705	4705		
	28	34384	11.25	9495	26448.75	8	37640	56460	**164427.8**	**6.217184**
2A-1										
		1408		554	2351		4705	4705		
	11.25	15840	11.25	6232.5	26448.75	8	37640	56460	**142621.3**	**7.167778**
2A-2										
		1408		554	2351		4705	4705		
	8	11264	11.25	6232.5	26448.75	8	37640	56460	**138045.3**	**7.40538**

2A-3										
		1408		554	2351		4705	4705		
	11.25	15840	11.25	6232.5	26448.75	8	37640	18820	**104981.3**	**9.737715**
2B-1										
		1408		554	2351		4705	4705		
	28	39424	11.25	6232.5	26448.75	8	37640	56460	**166205.3**	**6.150693**
3A-1										
		860		724	2164		4705	4705		
	11.25	9675	11.25	8145	24345	8	37640	56460	**136265**	**7.502128**
3A-2										
		860		724	2164		4705	4705		
	8	6880	11.25	8145	24345	8	37640	56460	**133470**	**7.659231**
4A-1										
		834		810	2351		4705	4705		
	11.25	9382.5	11.25	9112.5	26448.75	8	37640	56460	**139043.8**	**7.3522**
4A-2										
		834		810	2351		4705	4705		
	8	6672	11.25	9112.5	26448.75	8	37640	56460	**136333.3**	**7.498373**
1A-1										

LOCATE.XLS

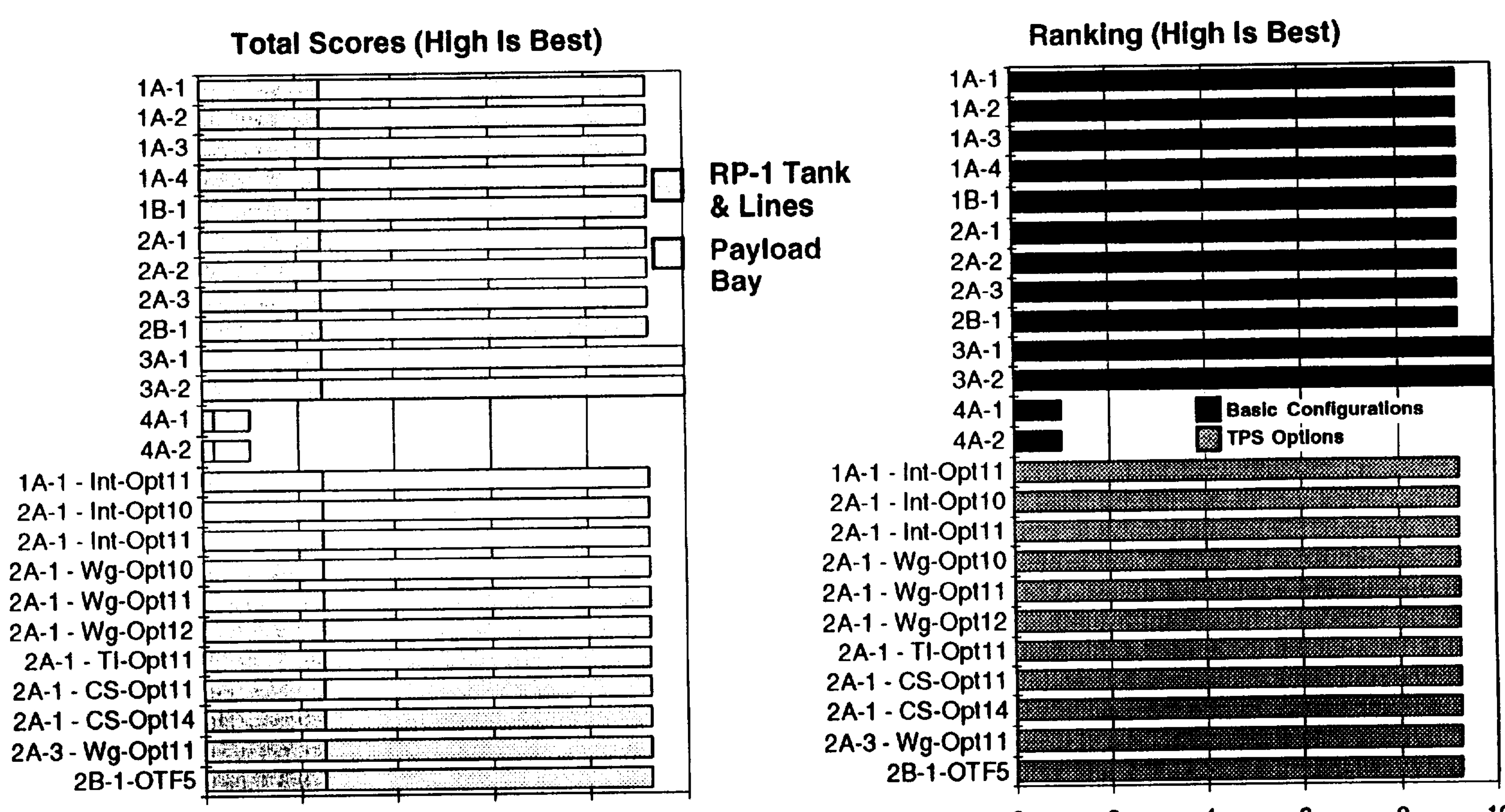
INT 11		1228		844	2351		4705	4705		
	11.25	13815	11.25	9495	26448.75	8	37640	56460	**143858.8**	**7.10612**
2A-1										
INT 10		1408		554	2351		4705	4705		
	11.25	15840	11.25	6232.5	26448.75	8	37640	56460	**142621.3**	**7.167778**
2A-1										
INT 11		1408		554	2351		4705	4705		
	11.25	15840	11.25	6232.5	26448.75	8	37640	56460	**142621.3**	**7.167778**
2A-1										
WG 10		1408		554	2351		4705	4705		
	11.25	15840	11.25	6232.5	26448.75	16	75280	56460	**180261.3**	**5.671088**
2A-1										
WG 11		1408		554	2351		4705	4705		
	11.25	15840	11.25	6232.5	26448.75	8	37640	56460	**142621.3**	**7.167778**
2A-1										
WG 12		1408		554	2351		4705	4705		
	11.25	15840	11.25	6232.5	26448.75	10	47050	56460	**152031.3**	**6.724127**
2A-1										
TL 11		1408		554	2351		4705	4705		
	11.25	15840	11.25	6232.5	26448.75	8	37640	56460	**142621.3**	**7.167778**

2A-1										
CS 11		1408		554	2351		4705	4705		
	11.25	15840	11.25	6232.5	26448.75	8	37640	56460	**142621.3**	**7.167778**
2A-1										
CS 14		1408		554	2351		4705	4705		
	11.25	15840	11.25	6232.5	26448.75	20	94100	56460	**199081.3**	**5.134976**
2A-3										
WG 11		1408		554	2351		4705	4705		
	11.25	15840	11.25	6232.5	26448.75	8	37640	18820	**104981.3**	**9.737715**
2B-1		1408		554	2351		4705	4705		
OTF 5	28	39424	11.25	6232.5	26448.75	28	131740	56460	**128565.3**	**7.951429**

Option 3 Ranked Best For Accessibility

SSTO

7c. Accessibility - (Qualitative Analysis) - The candidate vehicle options are compared based on the ease of accessibility to inspect, monitor and maintain the structural elements.



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LH2 TANK & LINES

Configuration 1A: LH2 Tank FWD (Integral)

By definition, Integral means that there are no cavities between the tank and the fuselage structure. Therefore, during a 7 day (or less) ground turnaround, there will be no inspection of that area. An inner tank inspection can be performed through the "dollar panel." This panel normally houses the sump hardware. The sump hardware must be removed for borescope access or other robotics device to check the condition of the inner tank structure. It may also be possible to gain access to the inner tank through a tank line.

The tank may have two kinds of sensors, Quantity and Density sensors. The Quantity sensor is a tube-like device which is used to measure tank level and if failed, can be repaired through the dollar panel/access panel.

The Density sensor is used to measure the mass of the fuel or oxidizer. It is a block shaped piece of hardware bolted and sealed to the inner tank wall. If failed, removal and replacement would require disassembling parts of the fuselage, insulation, and the opening of a panel which houses the sensor block. This would not be minor and would not support a 7 day turnaround.

The scores were low for the LH2 tank because of the limited access, i.e., dollar panel with sump hardware remove and replace required or access through tank lines.

Configuration 2A: LH2 Tank AF (Integral)

The tank may be 2/3 Integral with 1/3 bottom faring & carriage. This would require access to the exterior tank areas for inspection. With this exception, the description of LH2 Tank FWD for Configuration 1A holds true.

Configuration 3,4: LH2 Tank FWD (Integral)

The description given for Configuration 1A applies here as well.

LO2 TANK & LINES

Configuration 1A,3,4: LO2 Tank AF (Integral)

The Description for LH2 Configuration 1A and LH2 Configuration 2A apply to this LO2 configuration.

Configuration 2A: LO2 Tank FWD (Integral)

The description for LH2 Configuration 1A applies.

RP-1 TANK & LINES

Configuration 1A, 2A: RP-1 Tank Middle (Floating, and under Payload Bay)

The RP-1 Tank will have space between the external tank wall and the fuselage which will require inspection. Access will be through the fuselage and/or the Payload Bay area.

Interior tank access for inspection will be through a Dollar Panel or tank lines.

Configuration 3: RF-1 Tank FWD (Floating and under Payload Bay)

Same as 1A & 2A above.

Configuration 4: RF-1 Tank AFT (Floating and under Payload Bay)

Same as 1A & 2A except for the added potential conflict with other mechanical/Global Positioning Satellite (GPS) activities which may be needed in and around the Wings, Tails, and MPS areas.

This configuration was Scored lower because of access and potential access problems.

ENGINE COMPONENTS

All Configurations:

There is an Engine MPS cone. Outside the cone are mounted the Engines (7 RD704s) and all their components. There are furthermore panels which enclose the components for protection. Opening these panels provide easy access to engine Turbo Pumps, and other components.

Access to these areas is good and will only require the appropriate GSE (work stands, tools, etc.).

MPS FEED LINES
All Configuration:

Between the Engines there is an access door to the cone where inspection is required.

Access to these areas is good and will only require the appropriate GSE (work stands, tools, etc.).

AVIONICS - UNPRESSURIZED

The Avionics Bays are located along the sides of the Nose Wheel Landing Gear Wheel Well wall access during ground turnaround. The location accommodates 24 square feet of "one-box-deep" volume on either side of the Wheel Well. One goal is Passive Cooling to eliminate Coldplate Systems. Another goal is to be able to install all Avionics in the unpressurized area.

AVIONICS - PRESSURIZED

There may be a compartment/cell where Partial-Atmospheric will hold a few Avionics boxes. Access and satisfactory reconfiguration and test will make this area more difficult/complex during the process timeline.

The Score was lower than Unpressurized Avionics because of the increased complexity of removal and replacement.

OMS (AFT)
All Configurations:

In general, accessibility is the same as for all vehicle configurations.

RCS (FWD AND AFT)

All Configurations:
In general, accessibility is the same for all vehicle configurations.

PAYLOAD BAY

Configurations 1A, 2A, 3: Payload Bay Placement at Mid-Body and Nose

In general, accessibility is the same, perhaps slightly better for Configuration 3 where the Payload Bay is forward and near the vehicle nose.

Configuration 4: Payload Bay AFT and over the Wing

This is judged to be more complex than the other configurations due to the proximity to the Wings and Tails where a work conflict could develop.

The Score was lower due to potential conflict with other processing components.

CONTROL SURFACES - WINGS

All Configurations:

In general, access is good to these surfaces.

CONTROL SURFACES - TAILS

All Configurations:
In general, the appropriate ground support equipment (GSE) will make these surfaces accessible.

GROUND CONNECTORS

All Configurations:
In general, access is good to vehicle connectors in the Horizontal Processing Facilities (HPF).

ELECTRICAL SYSTEMS

Batteries

All Configurations:
The location of the Batteries will be AFT around the Wing and near the Main Landing Gear. The Batteries are needed for the high amperage required by the EMA's, e.g., cycling elevons.
Accessibility will be the same for all vehicle configurations.

Wire/Fiber Optics

All Configurations:
For Power, Copper Wire is still planned. Fiber Optics is planned for Signal paths.
There will be wire bundles from one end of the vehicle to the other providing Power and Control and Data. Access in all configurations will be difficult for inspection and repair.

Scoring was not high for access but design for better access may not be practical considering other impacts, e.g., cost of design, fabrication, and maintenance.

Emergency Beacon

All Configurations:
An Emergency Locator Beacon is needed in the event of a vehicle crash.
Accessibility will be the same for all vehicle configurations.

Navigation Lights & Lighting System

All Configurations:
There will be Antennas in the Nose and the rear of the vehicle. Advanced Tiles with embedded Antennas will be scattered around these areas. Special access procedures and handling may be required. The difficulty will be the same for all configurations.

Accessibility

TPS
All Configurations:
Accessibility will be the same for all configurations. The type and requirements for inspections, repair, remove and replace, and re-waterproofing will drive the extent of processing.

SMART SKINS
All Configurations:
Complex tiles with embedded Smart Skins may be difficult to access.

TELEVISION SYSTEMS
All Configurations:
Accessibility will be the same for all configurations.

LANDING GEAR AND BRAKES
All Configurations.
Accessibility will be the same for all configurations.

Summary - Accessibility

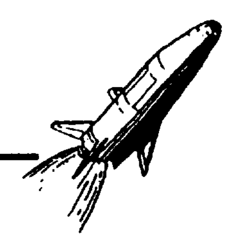
Configuration		1A-1		1A-2		1A-3		1A-4		1B-1		2A-1		2A-2	
Selection Criteria	Wt	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
LH2 Tank & Lines		3.0		3.0		3.0		3.0		3.0		3.0		3	
LO2 Tank & Lines		3.0		3.0		3.0		3.0		3.0		3.0		3	
RP-1 Tank & Lines	25%	10.0	2.5	10.0	2.5	10.0	2.5	10.0	2.5	10.0	2.5	10.0	2.5	10	2.5
Engines Components		10.0		10.0		10.0		10.0		10.0		10.0		10	
MPS Feed Lines		10.0		10.0		10.0		10.0		10.0		10.0		10	
Avionics - Unpressurized		10.0		10.0		10.0		10.0		10.0		10.0		10	
Avionics - Partial Press		5.0		5.0		5.0		5.0		5.0		5.0		5	
OMS (AFT)		10.0		10.0		10.0		10.0		10.0		10.0		10	
RCS (Forward & AFT)		10.0		10.0		10.0		10.0		10.0		10.0		10	
Payload Bay	75%	9.0	6.8	9.0	6.8	9.0	6.8	9.0	6.8	9.0	6.8	9.0	6.8	9	6.8
Control Surfaces-Wings		10.0		10.0		10.0		10.0		10.0		10.0		10	
Control Surfaces - Tails		5.0		5.0		5.0		5.0		5.0		5.0		5	
EMA's (All)		5.0		5.0		5.0		5.0		5.0		5.0		5	
Ground Connectors		10.0		10.0		10.0		10.0		10.0		10.0		10	
Electrical Systems															
o Batteries		10.0		10.0		10.0		10.0		10.0		10.0		10	
o Wire/Fiber Optics		5.0		5.0		5.0		5.0		5.0		5.0		5	
o Emergency Beacon		10.0		10.0		10.0		10.0		10.0		10.0		10	
o Nav Lights & Light Sys		10.0		10.0		10.0		10.0		10.0		10.0		10	
Antennas		10.0		10.0		10.0		10.0		10.0		10.0		10	
TPS		10.0		10.0		10.0		10.0		10.0		10.0		10	
Smart Skins		2.0		2.0		2.0		2.0		2.0		2.0		2	
Televisions Systems		8.0		8.0		8.0		8.0		8.0		8.0		8	
Landing Gear & Brakes		10.0		10.0		10.0		10.0		10.0		10.0		10	
Total Wt'd Score	100%		9.3		9.3		9.3		9.3		9.3		9.3		9.3

Configuration	2A-3		2B-1		3A-1		3A-2		3A-3		4A-1		4A-2	
Selection Criteria	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
LH2 Tank & Lines	3		3		3		3		3		3		3	
LO2 Tank & Lines	3		3		3		3		3		3		3	
RP-1 Tank & Lines	10	2.5	10	2.5	10	2.5	10	2.5	10	2.5	1	0.3	1	0.3
Engines Components	10		10		10		10		10		10		10	
MPS Feed Lines	10		10		10		10		10		10		10	
Avionics - Unpressurized	10		10		10		10		10		10		10	
Avionics - Partial Press	5		5		5		5		5		5		5	
OMS (AFT)	10		10		10		10		10		10		10	
RCS (Forward & AFT)	10		10		10		10		10		10		10	
Payload Bay	9	6.8	9	6.8	10	7.5	10	7.5	10	7.5	1	0.8	1	0.8
Control Surfaces-Wings	10		10		10		10		10		10		10	
Control Surfaces - Tails	5		5		5		5		5		5		5	
EMA's (All)	5		5		5		5		5		5		5	
Ground Connectors	10		10		10		10		10		10		10	
Electrical Systems														
o Batteries	10		10		10		10		10		10		10	
o Wire/Fiber Optics	5		5		2		2		2		2		2	
o Emergency Beacon	10		10		10		10		10		10		10	
o Nav Lights & Light Sys	10		10		10		10		10		10		10	
Antennas	10		10		10		10		10		10		10	
TPS	10		10		10		10		10		10		10	
Smart Skins	2		2		2		2		2		2		2	
Televisions Systems	8		8		8		8		8		8		8	
Landing Gear & Brakes	10		10		10		10		10		10		10	
Total Wt'd Score		9.3		9.3		10.0		10.0		10.0		1.0		1.0

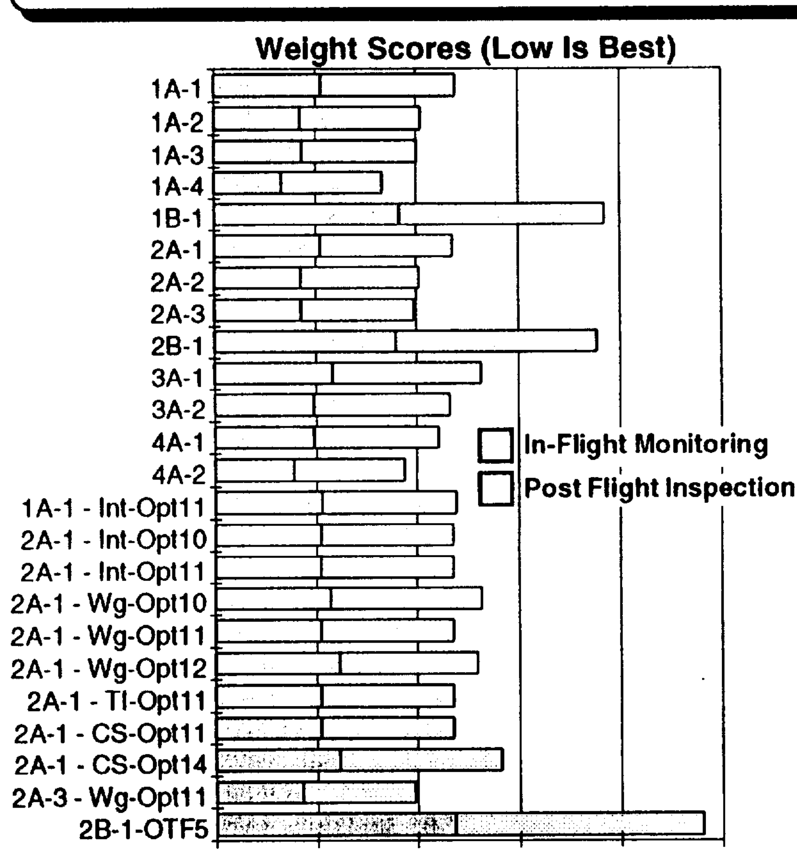
Configuration		1A-1 - Int-Opt11		2A-1 - Int-Opt10		2A-1 - Int-Opt11		2A-1 - Wg-Opt10		2A-1 - Wg-Opt11		2A-1 - Wg-Opt12		2A-1 - Tl-Opt11		2A-1 - CS-Opt11		2A-1 - CS-Opt14		2A-3 - Wg-Opt11		2B-1-OTF5	
Selection Criteria	Wt	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
LH2 Tank & Lines		3		3		3		3		3.0		3.0		3.0		3.0		3.0		3.0		3.0	
LO2 Tank & Lines		3		3		3		3		3.0		3.0		3.0		3.0		3.0		3.0		3.0	
RP-1 Tank & Lines	25%	10	2.5	10	2.5	10	2.5	10	2.5	10.0	2.5	10.0	2.5	10.0	2.5	10.0	2.5	10.0	2.5	10.0	2.5	10.0	2.5
Engines Components		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
MPS Feed Lines		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Avionics - Unpressurized		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Avionics - Partial Press		5		5		5		5		5.0		5.0		5.0		5.0		5.0		5.0		5.0	
OMS (AFT)		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
RCS (Forward & AFT)		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Payload Bay	75%	9	6.8	9	6.8	9	6.8	9	6.8	9.0	6.8	9.0	6.8	9.0	6.8	9.0	6.8	9.0	6.8	9.0	6.8	9.0	6.8
Control Surfaces-Wings		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Control Surfaces - Tails		5		5		5		5		5.0		5.0		5.0		5.0		5.0		5.0		5.0	
EMA's (All)		5		5		5		5		5.0		5.0		5.0		5.0		5.0		5.0		5.0	
Ground Connectors		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Electrical Systems																							
o Batteries		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
o Wire/Fiber Optics		5		5		5		5		5.0		5.0		5.0		5.0		5.0		5.0		5.0	
o Emergency Beacon		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
o Nav Lights & Light Sys		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Antennas		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
TPS		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Smart Skins		2		2		2		2		2.0		2.0		2.0		2.0		2.0		2.0		2.0	
Televisions Systems		8		8		8		8		8.0		8.0		8.0		8.0		8.0		8.0		8.0	
Landing Gear & Brakes		10		10		10		10		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Total Wt'd Score	100%		9.3		9.3		9.3		9.3		9.3		9.3		9.3		9.3		9.3		9.3		9.3

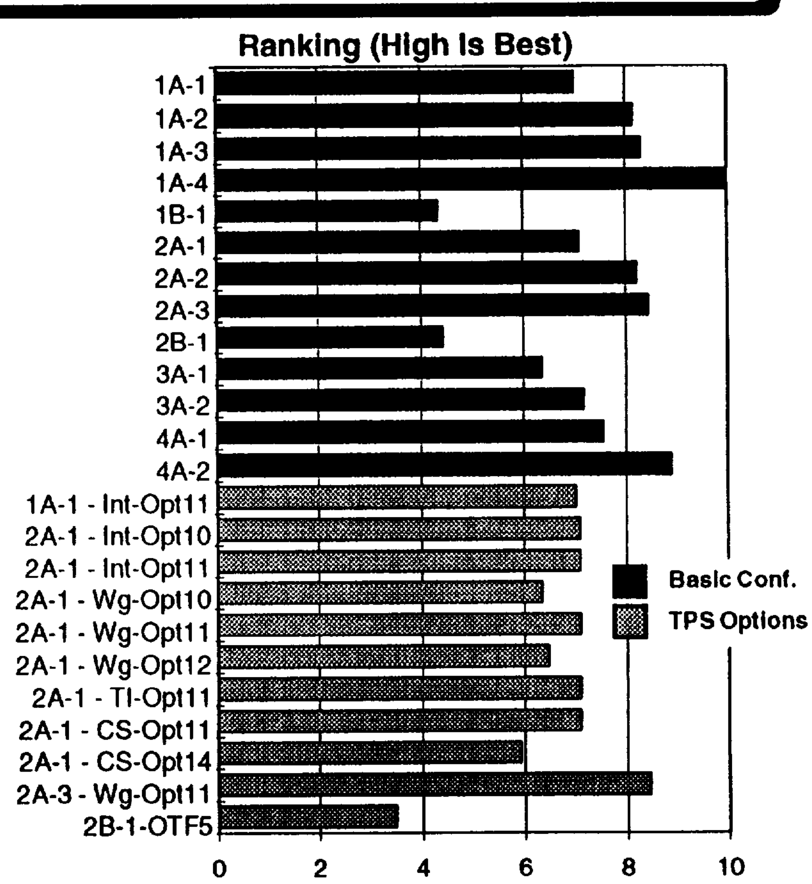
Option 1A-4 Ranked Best For Number Of Inspection Points

SSTO



7d. Number of inspection points - (Quantitative Analysis) - The candidate vehicle options are compared based on the number of elements that have to be inspected, monitored, and maintained during operations (i.e. sandwich construction with multiple bondlines will potentially have more inspection requirements)





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MAINTENANCE OPERATIONS - Number of Inspection Points

The candidate vehicle options are compared based on the number of elements that have to be inspected, monitored and maintained during operations. For example stringer skin constructions have a limited number of components (skin and TPS layers). However, the complexity of the design will cause more intensive instrumentation to monitor, more intensive inspections and more intensive maintenance. This category is assessed on the surface are that these structures (tanks) will cover. The rationale being that the more surface area the structure has of a particularly difficult design the more difficult the structure will be to inspect, monitor and maintain. The critical features of these designs were considered to be stringer/skin designs, non-integral designs and material selections.

In general, the maintenance operations-number of inspection points was based on several assumptions. These assumptions reflect the difficulties of inspection and instrumentation of the design configurations during the post-flight testing and in flight IHM instrumentation as applied to design and materials selections.

Design Assumptions

C-2

Several design considerations effect the ability of the structure to be inspected. Primary design considerations include the complexity of the design, the surface area to be inspected, the number of fracture critical components and the number of components to be inspected of instrumented.

Complexity of design

Inherently, simple designs tend to be better suited to inspection and instrumentation than do complex designs. The more complex designs, such as skin and stringer designs have a bend and protrusions that limit accessibility to hardware, inspection techniques, implementation and interpretation. It was also assumed that a more complex design may also require fabrication of specific tooling to facilitate inspection.

Surface Area

Since the NDI technologies to be employed by IHM/NDI are dependent on the area of coverage (rather than on the thickness of the hardware), larger surface areas would be more difficult to inspect and instrument. This infers that the elongated and multiple tank designs are more difficult to inspect and instrument. This also infers that since the non integral design configurations have an internal and external structure the area of surface coverage had effectively doubled.

Number of fracture critical components

The level of inspection will not be consistent over the entire vehicle. Fracture critical items (i.e. tank splices, stringers and fittings) will require more intensive inspections and instrumentation than less critical components. Therefore, design configurations that have the largest number of fracture critical components will require the largest number of inspections and instrumentations.

Number of components inspected

Non integrated design configurations have a larger surface area, are more complex and have more critical components. These problems directly effect the NDI/IHM programs by increasing the number of inspection points and area to be inspected.

Materials Assumptions

Due to a lack of information on the composite/TPS structures, it was assumed that the IM7/977-2, AFR 700, Gr/BMI, TMC composite materials and Al-Li alloys have approximately same adaptability to NDI/IHM techniques. In general, the TPS materials assumed that the flexible blanket insulation is considered non inspectable by means other than visual inspection and the C/SiC is more readily adaptable to NDI/IHM.

Critical feature factors

The primary number of components was considered to be the number of skins and TPS layers. The identification of a critical design or material in each of the vehicle structures were evaluated and assigned a critical feature factor. This factor reflects the effect the critical feature will have on the post flight inspections. It was generally considered that these variables would increase the difficulty of inspection by an order of magnitude for each critical factor.

The critical feature factor of stringer design evaluation as applied to in-flight IHM monitoring indicated that This configuration has a greater number of critical points of instrumentation. The bond lines and corners associated with the stringer stiffeners are stress concentration points that would require a concentrated level of instrumentation. It is considered that the acoustic emission transducers would be concentrated along the stringers and that the configuration complexity would make the signals more difficult to interpret. A correction factor of 3.0 was applied to the stringer designs to compensate for these difficulties.

The critical feature factor of stringer design evaluation as applied to post-flight inspections indicated that due to the tight bend radius would be difficult to evaluate using NDI techniques. Current laser based ultrasonics only allow for 30 degree angle from the inspection

plane. This indicates that complex tooling would be required for inspection. This configuration has a greater number of critical points of interest. The bond lines and corners are stress concentration points that would require a concentrated level of inspection. A correction factor of 3.75 was applied to the stringer designs to compensate for these difficulties.

The critical feature factor of non integral design evaluation as applied to in flight IHM monitoring indicated that these designs have multiple skins would effectively double the area for instrumentation. This design also increases the number of bond lines and a support structure for the internal tank that would increase the number of critical instumentation points. A correction factor of 2.0 was applied to non intergral designs to compensate for these difficulties

The critical feature factor of non integral design evaluation as applied to post flight inspections indicated that these designs have multiple skins would effectively double the area for instrumentation. This design also increases the number of bond lines and adds a support structure for the internal tank that would increase the number of critical inspection points. A correction factor of 2.0 was applied to non integral designs to compensate for these difficulties.

The critical feature factor of designs that utilize ceramic composites (Blackglas) as applied to in flight IHM monitoring indicated that there has been limited application of NDI techniques applied to ceramic composites. However, since IHM will most likely involve strain measuring devices and acoustic emission, there is no reason to believe that this composite material will interfere with these techniques. A correction factor of 1.0 was applied to composite designs to compensate for these difficulties.

The critical feature factor of designs that utilize ceramic composites (Blackglas) as applied to post flight inspections indicated that there has been limited application of NDI techniques applied to ceramic composites. This indicated that inspection of this material may require advanced techniques or development of techniques. A correction factor of 2.0 was applied to ceramic composite designs to compensate for these difficulties.

The critical feature factor of designs that utilize TABI or AFRSI blankets as applied to in flight IHM monitoring indicated that there has been limited application of NDI techniques applied to TABI or AFRSI blankets. This indicated that inspection of this material may require advanced techniques or development of techniques. It is also expected that if these techniques cannot be developed and the blankets will not be monitored during flight. Therefore no correction is necessary (a correction factor of 1.0) for designs with TABI or AFRSI blankets.

The critical feature factor of designs that utilize TABI or AFRSI blankets as applied to post flight inspections indicated that there has been limited application of NDI techniques applied to TABI or AFRSI blankets. This indicated that inspection of this material may require advanced techniques or development of techniques. It is also expected that if these techniques cannot be developed the blankets

will require a complete visual inspection. A correction factor of 1.5 was applied to designs with TABI or AFRSI blankets to compensate for these difficulties.

The critical feature factor of designs with TPS mechanical attachment evaluation, as applied to in flight IHM monitoring, indicated that due to additional stress concentration points and the associated gap would be difficult to evaluate using NDI techniques. This configuration has a greater number of critical points of interest. These stress concentration points would require a concentrated level of inspection. A correction factor of 2.0 was applied to these designs to compensate for these difficulties.

The critical feature factor of designs with TPS mechanical attachment evaluation, as applied to post-flight inspections, indicated that due to additional stress concentration points and the associated gap would be difficult to evaluate using NDI techniques. This configuration has a greater number of critical points of interest. These stress concentration points would require a concentrated level of inspection. A correction factor of 2.0 was applied to these designs to compensate for these difficulties.

Trade study process

The trade study estimated the critical points of inspection on each vehicle configuration by the estimated tank splice areas. Double this area was multiplied by its critical feature factor to rate the effect this structure type has on the vehicles score. The trade study estimated the general points of inspection on each vehicle configuration by the estimated tank surface areas. Since the general points make up the majority of the inspections, the general areas were weighted heavier than the critical areas. Due to the similarities between designs, the wing, nose, canard, payload canister areas are not included in this investigation.

The combined critical feature factor for each structure option was arrived through the following calculation:
No. of skins + No. of TPS layers = Subtotal
Subtotal X Critical Feature Factor = Combined Critical Feature Factor

Table 1. Estimated Surface Areas of Tanks

Configuration	LH2 Tank General	LH2 Tank Critical	LO2 Tank General	LO2 Tank Critical	RP Tank General
1A&B	6940	614	4565	422	1593
2A&B	6509	704	4805	277	1593
3	6591*	430	3250*	362	6190
4	7214*	417	3002*	405	1593

Structure/TPS design analysis

The structures were rated according to its 1) No. of skins, 2) No. of TPS layers and 3) Critical feature factor for each of the three phases of the structures life. The critical feature factor corrects for complicated design features,(stringer and non integrated designs) and material deficiencies (ceramic composites and AFRI or TABI blankets) as applied to the NDE/IHM project. It was generally considered that these variables would increase the difficulty of inspection by an order of magnitude.

Table 2. Number of variables and applied difficulty factor

Trade Option	No. of skins	No. of TPS layers	Sub total	IHM in-flight Critical Feature Factor	Post-flight Critical Feature factor
1	1	2	3	3.0	3.75
2	2	2	4	1.0	2.0
5	4	3	7	4.0	4.0.0
7	4	3	7	4.0	4.0
8	1	2	3	3.0	3.75
9	2	2	4	1.0	2.0
10	2	2	4	2.0	2.0
11	2	2	4	1.0	2.0
12	1	1	2	6.0	5.0
13	1	1	2	3.0	3.75
14	1	1	2	6.0	10.0

Table 3. Critical Feature Factors

Design deficiency	Fabrication	IHM	Post-flight
Stringer design	2.0	3.0	3.75
non integral design	2.0	2.0	2.0
ceramic materials*	1.5	1.0	2.0
AFRI or TABI	1.0	1.0	1.5
TPS mechanical attachment**			

*Blackglas Option 14
**Options 5, 10, 12 and 14

Table 4. Combined Critical Feature Factors

OPTION	Combined Critical Feature Factor for In-flight IHM	Combined Critical Feature Factor for Post-flight Inspection
1	9.0	11.25
2	4	8
5	28	28
7	28	28
8	9.0	11.25
9	4	8
10	8.0	8.0
11	4	8
12	12	10
13	6	7.5
14	12	20

POINTS.XLS

CONFIG		CRITICAL FEATURE FACTOR	LH2 GENERAL AREA	LH2 CRITICAL AREA	CRITICAL FEATURE FACTOR	LO2 GENERAL AREA	LO2 CRITICAL AREA	RP GENERAL AREA	CRITICAL FEATURE FACTOR	WING GENERAL AREA	WING ATTACH FACTOR	TOTALS	**RATING**
1A-1			6940	1228		4565	844	1593		4705	4705		
	IHM	9	62460	11052	9	41085	7596	14337	4	18820	56460	211810	
	POST	11.25	78075	13815	11.25	51356.25	9495	17921.25	8	37640	56460	264762.5	
												476572.5	**7.006583**
1A-2			6940	1228		4565	844	1593		4705	4705		
	IHM	4	27760	4912	9	41085	7596	14337	4	18820	56460	170970	
	POST	8	55520	9824	11.25	51356.25	9495	17921.25	8	37640	56460	238216.5	
												409186.5	**8.160448**
1A-3			6940	1228		4565	844	1593		4705	4705		
	IHM	9	62460	11052	9	41085	7596	14337	4	18820	18820	174170	
	POST	11.25	78075	13815	11.25	51356.25	9495	17921.25	8	37640	18820	227122.5	
												401292.5	**8.320975**
1A-4			6940	1228		4565	844	1593		4705	4705		
	IHM	4	27760	4912	9	41085	7596	14337	4	18820	18820	133330	
	POST	8	55520	9824	11.25	51356.25	9495	17921.25	8	37640	18828	200584.5	
												333914.5	**10**
1B-1			6940	1228		4565	844	1593		4705	4705		
	IHM	28	194320	34384	9	41085	7596	14337	4	18820	56460	367002	
	POST	28	194320	34384	11.25	51356.25	9495	17921.25	8	37640	56460	401576.5	
												768578.5	**4.344572**
2A-1			6509	1408		4805	554	1593		4705	4705		
	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												470477.3	**7.097357**

POINTS.XLS

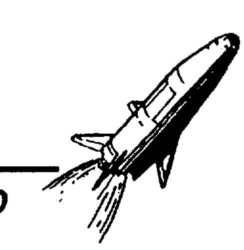
2A-2			6509	1408		4805	554	1593		4705	4705		
	IHM	4	26036	5632	9	43245	4986	14337	4	18820	56460	169516	
	POST	8	52072	11264	11.25	54056.25	6232.5	17921.25	8	37640	56460	235646	
												405162	**8.241506**
2A-3			6509	1408		4805	554	1593		4705	4705		
	IHM	9	58581	12672	9	43245	4986	14337	4	18820	18820	171461	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	18820	223736.3	
												395197.3	**8.449312**
2B-1			6509	1408		4805	554	1593		4705	4705		
	IHM	28	182252	39424	9	43245	4986	14337	4	18820	56460	359524	
	POST	28	182252	39424	11.25	54056.25	6232.5	17921.25	8	37640	56460	393986	
												753510	**4.431454**
3A-1			6591	860		3250	724	6190		4705	4705		
	IHM	9	59319	7740	9	29250	6516	55710	4	18820	56460	233815	
	POST	11.25	74148.75	9675	11.25	36562.5	8145	69637.5	8	37640	56460	292268.8	
												526083.8	**6.347174**
3A-2			6591	860		3250	724	6190		4705	4705		
	IHM	4	26364	3440	9	29250	6516	55710	4	18820	56460	196560	
	POST	8	52728	6880	11.25	36562.5	8145	69637.5	8	37640	56460	268053	
												464613	**7.186938**
3A-3			6591	860		3250	844	6190		4705	4705		
	IHM	4	26364	3440	9	29250	7596	55710	4	18820	18820	160000	
	POST	8	52728	6880	11.25	36562.5	9495	69637.5	8	37640	18820	231763	
												391763	**8.52338**
4A-1			7214	834		3002	810	1593		4705	4705		
	IHM	9	64926	7506	9	27018	7290	14337	4	18820	56460	196357	
	POST	11.25	81157.5	9382.5	11.25	33772.5	9112.5	17921.25	8	37640	56460	245446.3	
												441803.3	**7.557991**

4A-2			7214	834		3002	810	1593		4705	4705		
	IHM	4	28856	3336	9	27018	7290	14337	4	18820	56460	156117	
	POST	8	57712	6672	11.25	33772.5	9112.5	17921.25	8	37640	56460	219290.3	
												375407.3	**8.894727**
1A-1			6940	1228		4565	844	1593		4705	4705		
INT 11	IHM	9	62460	11052	9	41085	7596	14337	4	18820	56460	211810	
	POST	11.25	78075	13815	11.25	51356.25	9495	17921.25	8	37640	56460	264762.5	
												476572.5	**7.006583**
2A-1			6509	1408		4805	554	1593		4705	4705		
INT 10	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												470477.3	**7.097357**
2A-1			6509	1408		4805	554	1593		4705	4705		
INT 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												470477.3	**7.097357**
2A-1			6509	1408		4805	554	1593		4705	4705		
WG 10	IHM	9	58581	12672	9	43245	4986	14337	8	37640	56460	227921	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	16	75280	56460	299016.3	
												526937.3	**6.336893**
2A-1			6509	1408		4805	554	1593		4705	4705		
WG 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												470477.3	**7.097357**
2A-1			6509	1408		4805	554	1593		4705	4705		
WG 12	IHM	9	58581	12672	9	43245	4986	14337	12	56460	56460	246741	

POINTS.XLS

	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	10	47050	56460	270786.3	
												517527.3	**6.452114**
2A-1			6509	1408		4805	554	1593		4705	4705		
TL 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												470477.3	**7.097357**
2A-1			6509	1408		4805	554	1593		4705	4705		
CS 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												470477.3	**7.097357**
2A-1			6509	1408		4805	554	1593		4705	4705		
CS 14	IHM	9	58581	12672	9	43245	4986	14337	12	56460	56460	246741	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	20	94100	56460	317836.3	
												564577.3	**5.914416**
2A-3			6509	1408		4805	554	1593		4705	4705		
WG 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	18820	171461	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	18820	223736.3	
												395197.3	**8.449312**
2B-1			6509	1408		4805	554	1593		4705	4705		
OTF 5	IHM	28	182252	39424	9	43245	4986	14337	28	131740	56460	472444	
	POST	28	182252	39424	11.25	54056.25	6232.5	17921.25	28	131740	56460	488086	
												960530	**3.476357**

Option 2A-1 CS-Opt11 Ranked Best For Fewest Re-Waterproofing Hours



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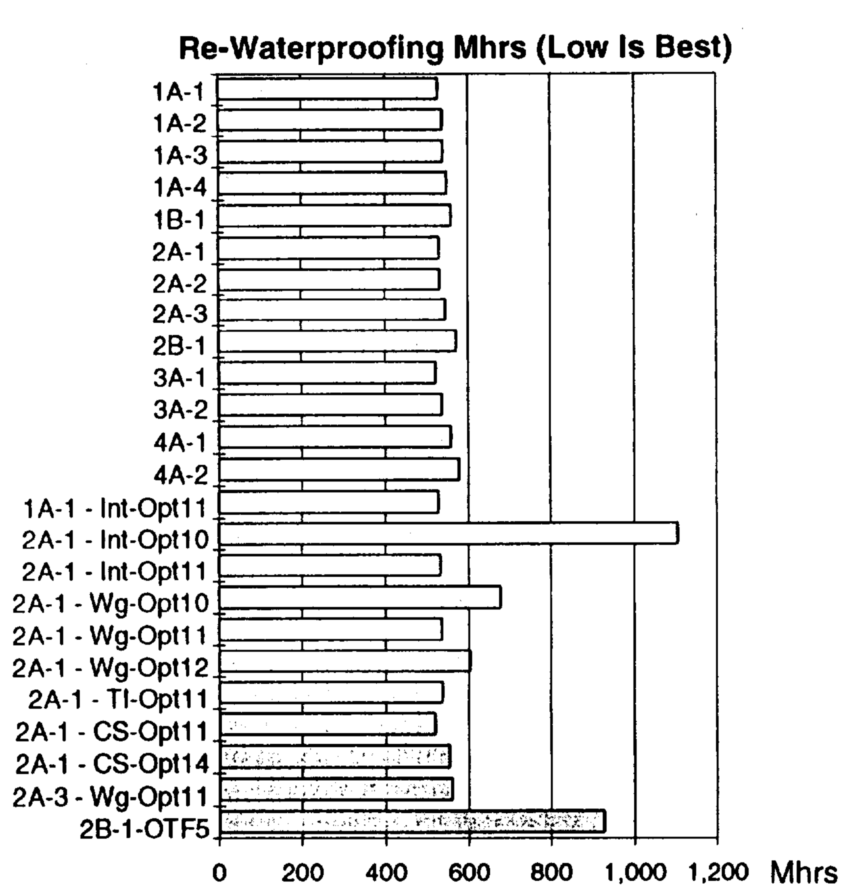
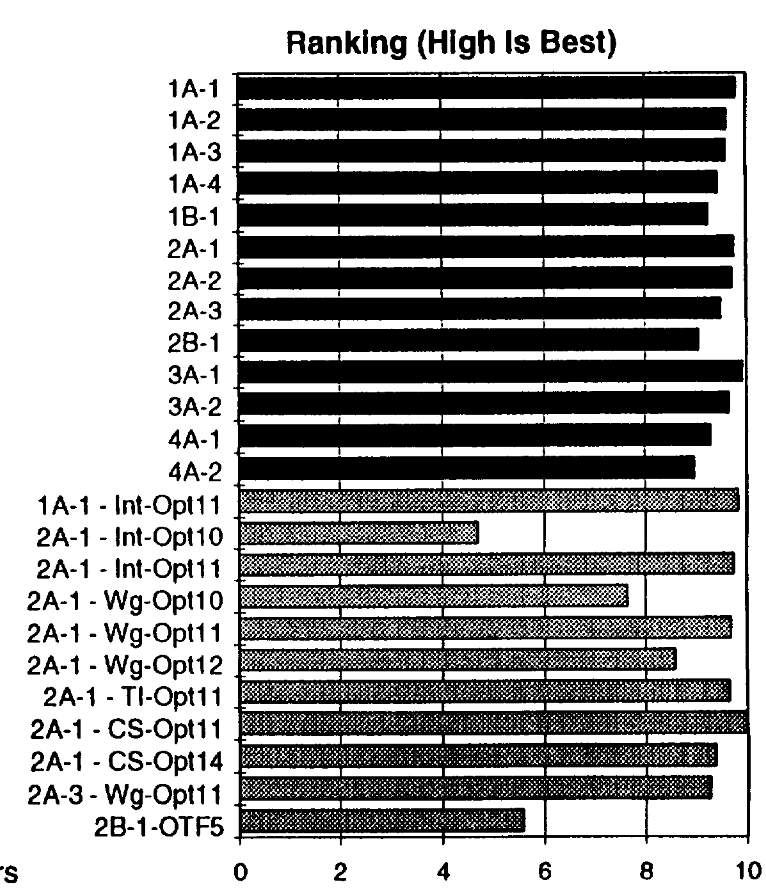
7e. Re-waterproofing-(Quantitative evaluation) - The candidate vehicle options are compared on the basis of the total time required, over 300 missions, to re-waterproof the TPS experiencing temperatures above 1100 F.





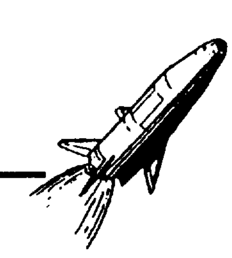
NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Re-Waterproofing

Configuration	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3	4A-1	4A-2
Scaling Factor	1.045	1.063	1.065	1.084	1.099	1.069	1.074	1.099	1.138	1.052	1.080	1.060	1.102	1.139
AFRSI (TOTAL)	15,838	15,838	15,838	15,838	15,987	16,238	16,238	16,238	16,015	15,060	15,060	15,060	15,246	15,246
Payload Canister AFRSI Not Requiring Re-Waterproofing	496	496	496	496	496	496	496	496	496	496	496	496	496	496
AETB	2,998	3,051	3,056	3,111	3,154	3,004	3,017	3,087	3,197	3,047	3,127	3,047	2,981	3,082
TABI	6,772	6,891	6,903	7,025	7,124	6,587	6,614	6,768	7,083	6,597	6,770	6,597	7,422	7,673
AFRSI (Requiring Re-Waterproofing)	3,030	3,083	3,088	3,143	3,242	3,261	3,274	3,350	3,527	2,999	3,078	3,020	3,075	3,179
Csic														

Configuration	1A-1 - Int-Opt11	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - TI-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
Scaling Factor	1.042	1.122	1.071	1.105	1.077	1.142	1.081	1.066	1.081	1.123	1.170
AFRSI (TOTAL)	15,471	11,618	15,879	14,628	16,238	14,628	16,238	15,738	15,738	16,238	13,269
Payload Canister AFRSI Not Requiring Re-Waterproofing	496	496	496	496	496	496	496	496	496	496	496
AETB	2,991	3,152	3,009	3,105	3,027	3,209	3,038	2,996	3,038	3,157	3,288
TABI	6,755	4,191	6,597	5,907	6,638	6,106	6,661	6,569	6,121	6,921	5,642
AFRSI (Requiring Re-Waterproofing)	3,022	2,995	3,266	1,204	3,286	1,199	3,298	2,986	3,028	3,426	2,493
Csic		7,309		2,774		1,839			541		4,915

Re-Waterproofing Manhours Calculated For TPS Seeing Over 1100ºF During Flight



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	Re-Waterprfg Rate	Reduction in area requiring Re-Waterproofing	
AFRSI	17.7 ft2/mhr	~~25%~~	Assumed Reduction
TABI	17.7 ft2/mhr	25%	Assumed Reduction
AETB	19.3 ft2/mhr	~~13%~~	~~From Draft TPS Report~~ - ave. tiles not rewaterproofed
Csic	10.8 ft2/mhr		5.6 Min/Pnl - Assume panel size 12 inches

* Payload Canister processed off line, including re-waterproofing. AFRSI area of Payload Canister not included.

AFRSI and TABI Re-waterproofing rates were assumed to be the same. The rate was calculated by averaging the square feet re-waterproofed per man hour for FI Blankets as supplied in Mike Gordon's draft TPS report.

AETB re-waterproofing rates were assumed to be the same as RSI tiles. The rate was calucleted by averagin the number of tiles/man hours re-waterproofed as supplied in Mike Gordon's draft TPS report.

Re-Waterproofing

Formulas

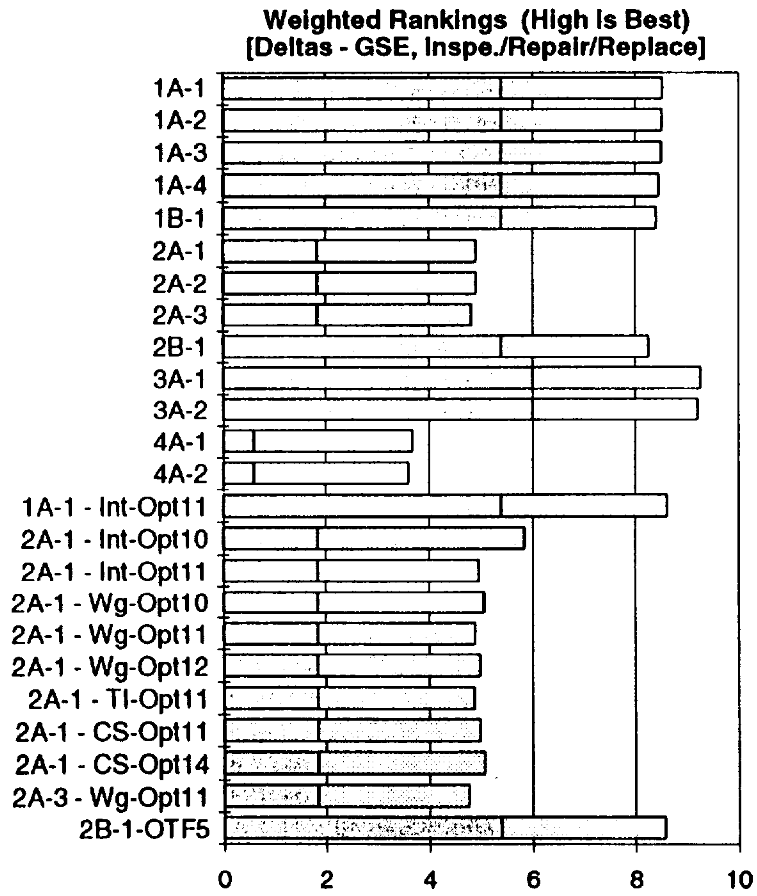
AETB = (sq ft) / (sq ft / mhr) * (1- reduction in area requiring re-waterproofing)
TABI = (sq ft) / (sq ft / mhr) * (1- reduction in area requiring re-waterproofing)
AFRSI = (sq ft) / (sq ft / mhr) * (1- reduction in area requiring re-waterproofing)
Csic = (sq ft) / (sq ft / mhr)

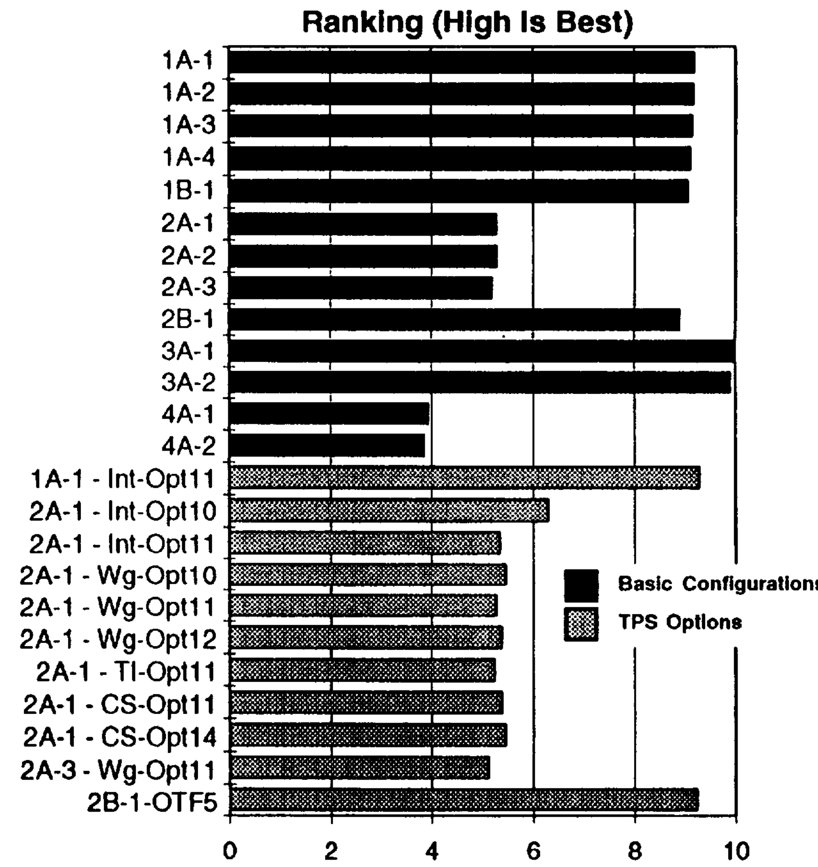
Re-Waterproofing	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3	4A-1	4A-2	1A-1 - Int-Opt11	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - Tl-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
AETB	134	137	137	139	141	135	135	138	143	136	140	136	134	138	134	141	135	139	136	144	136	134	136	141	147
TABI	287	292	293	298	302	279	281	287	301	280	287	280	315	326	287	178	280	251	282	259	283	279	260	294	239
AFRSI (Requiring Re-Waterproofing)	107	110	110	112	117	117	118	121	129	106	110	107	109	114	107	106	118	30	118	30	119	106	107	124	85
Csic																679		258		171			50		457
Total Manhours	529	539	540	550	560	531	534	546	572	523	537	523	558	577	528	1,105	532	678	536	604	538	519	553	559	928

3A Ranked Best For Sustained Personnel

SSTO

7f. Sustained personnel-(Quantitative evaluation) - The candidate vehicle options are compared on the determined number of technicians, and engineers required.





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Sustained Personnel

Configuration	1A-1 - Int-Opt1		2A-1 - Int-Opt10		2A-1 - Int-Opt11		2A-1 - Wg-Opt10		2A-1 - Wg-Opt11		2A-1 - Wg-Opt12	
Selection Criteria	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
GSE Delta	9.0	5.4	3.1	1.8	3.1	1.8	3.1	1.8	3.1	1.8	3.1	1.8
Acreage Delta (Insp., Repair, Replace)	8.0	3.2	10.0	4.0	7.8	3.1	8.0	3.2	7.6	3.0	7.9	3.1
Acreage Delta (Re-Waterproof)	9.7		1.0		9.6		6.0		9.5		7.6	
System Processing	-		-		-		-		-		-	
Total Wt'd Score		8.6		5.8		5.0		5.1		4.9		5.0
Ranking		9.3		6.3		5.3		5.4		5.3		5.4

Configuration	2A-1 - TI-Opt11		2A-1 - CS-Opt11		2A-1 - CS-Opt14		2A-3 - Wg-Opt11		2B-1-OTF5	
Selection Criteria	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
GSE Delta	3.1	1.8	3.1	1.8	3.1	1.8	3.1	1.8	9.0	5.4
Acreage Delta (Insp., Repair, Replace)	7.6	3.0	7.9	3.1	8.1	3.2	7.3	2.9	7.9	3.2
Acreage Delta (Re-Waterproof)	10.0		10.0		8.9		8.8		2.5	
System Processing	-		-		-		-		-	
Total Wt'd Score		4.9		5.0		5.1		4.8		8.6
Ranking		5.2		5.4		5.5		5.1		9.2

Sustained Personnel

Sustaining Personnel
Assumptions

1) Configurations require the same amount of manpower for ground processing of common systems (Avionic

2) Configurations with additional GSE requirements or with GSE that is larger or more complex, will require a meet scheduled turnaround goals

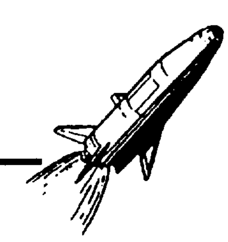
3) Configurations with more TPS acreage requiring inspection, repair, and replacement, and will require additi manpower to meet scheduled turnaround goals

4) Configurations with greater accessibility will not require additional manpower, but may impact scheduled tu

Configuration	1A-1		1A-2		1A-3		1A-4		1B-1		2A-1		2A-2	
Selection Criteria	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
GSE Delta	9.0	5.4	9.0	5.4	9.0	5.4	9.0	5.4	9.0	5.4	3.1	1.8	3.1	1.8
Acreage Delta (Insp., Repair, Replace)	7.8	3.1	7.8	3.1	7.7	3.1	7.6	3.1	7.5	3.0	7.7	3.1	7.7	3.1
Acreage Delta (Re-Waterproof)	9.7		9.4		9.3		9.0		8.7		9.6		9.5	
System Processing	-		-		-		-		-		-		-	
Total Wt'd Score		8.5		8.5		8.5		8.4		8.4		4.9		4.9
Ranking		9.2		9.2		9.1		9.1		9.1		5.3		5.3

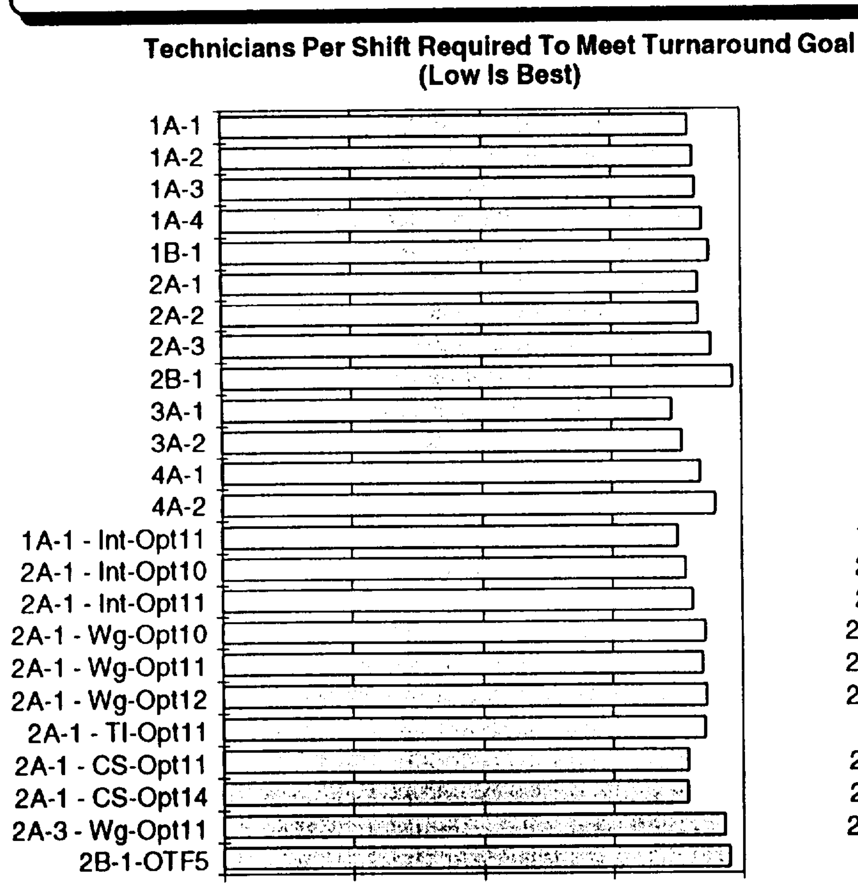
Configuration	2A-3		2B-1		3A-1		3A-2		3A-3		4A-1		4A-2	
Selection Criteria	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
GSE Delta	3.1	1.8	9.0	5.4	10.0	6.0	10.0	6.0	10.0	6.0	1.0	0.6	1.0	0.6
Acreage Delta (Insp., Repair, Replace)	7.4	3.0	7.2	2.9	8.1	3.3	8.0	3.2	8.2	3.3	7.7	3.1	7.5	3.0
Acreage Delta (Re-Waterproof)	9.1		8.4		9.9		9.4		9.8		8.8		8.3	
System Processing	-		-		-		-		-		-		-	
Total Wt'd Score		4.8		8.3		9.3		9.2		9.3		3.7		3.6
Ranking		5.2		8.9		10.0		9.9		10.0		3.9		3.9

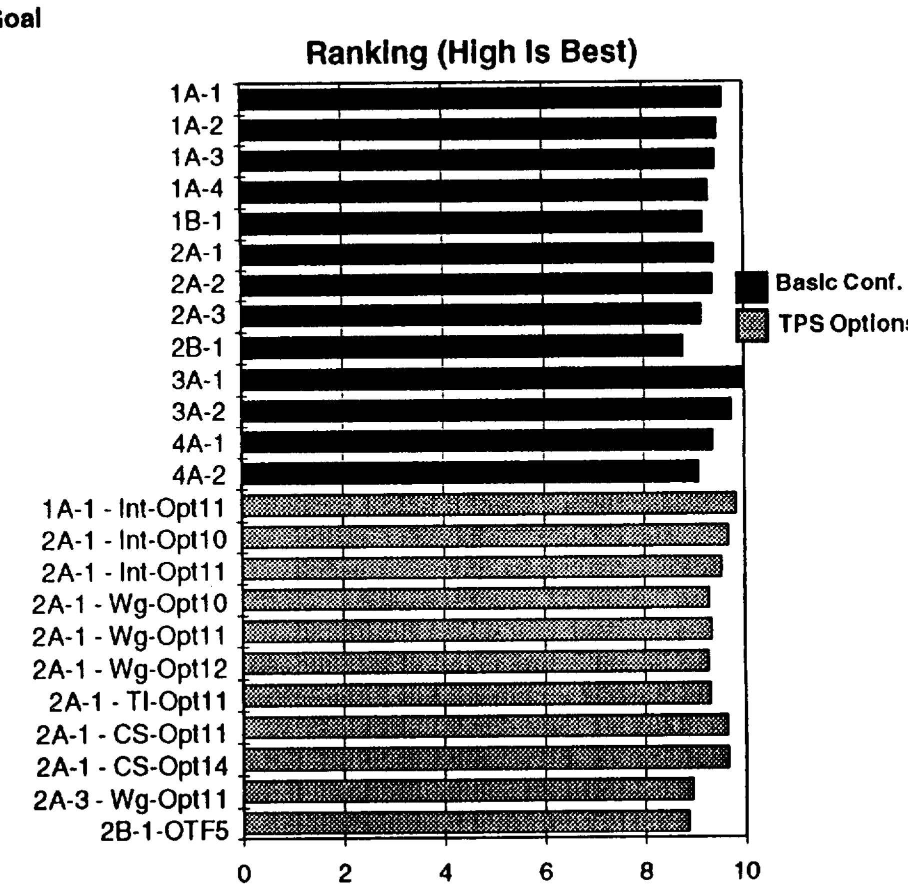
3A Ranked Best For Turnaround Time



SSTO

7g. Turn-around time - (Quantitative evaluation) - The candidate vehicle options are compared on the required time of turn around.





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21 Shifts For 7 Days
4 Shifts All Operations Not Performed In Parallel With TPS Maintenance
17 Shifts (Available for TPS Operations)
8 Hours Per Shift
136 Serial Hours => Hrs Per Shift * # Shifts
938 Minimum Hours = Configuration lowest Manhours
6.9 Techs Required Per Shift To Meet 17 Shift TPS Turn For Configuration With Lowest Manhours Requirement

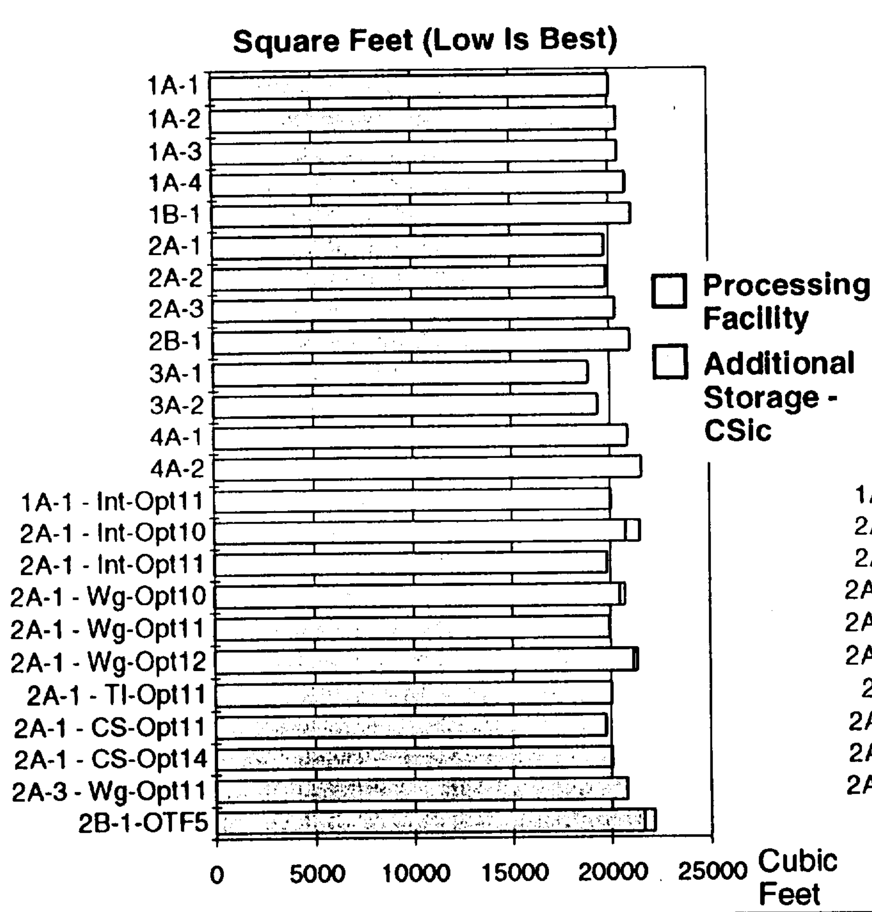
Configuration	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3	4A-1	4A-2	1A-1 - Int-Opt10
Inspection	601	612	613	624	633	615	617	632	660	584	599	584	621	642	591
Replacement	144	139	142	142	144	144	142	148	152	134	134	130	143	145	136
Repair	232	236	237	241	244	239	240	246	257	225	231	225	238	246	227
Re-Waterproofing (Not Included)	529	539	540	550	560	531	534	546	572	523	537	523	558	577	528
Total Hours	978	987	991	1007	1021	997	999	1025	1069	942	964	938	1002	1033	955
Technicians Req'd Per Shift	7.2	7.3	7.3	7.4	7.5	7.3	7.3	7.5	7.9	6.9	7.1	6.9	7.4	7.6	7.0
Ranking 10 & down	9.6	9.5	9.5	9.3	9.2	9.4	9.4	9.2	8.8	10.0	9.7	10.0	9.4	9.1	9.8

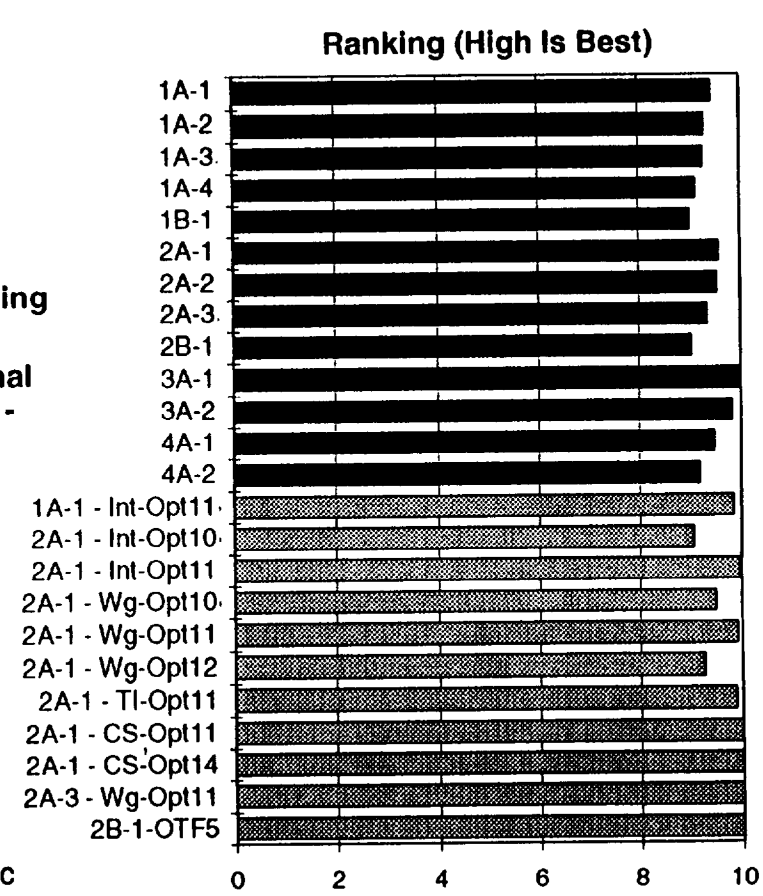
Configuration	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - Tl-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
Inspection	702	607	660	619	650	622	601	614	646	710
Replacement	82	141	128	145	132	146	140	125	151	134
Repair	186	235	223	241	231	242	233	233	251	216
Re-Waterproofing (Not Included)	1105	532	678	536	604	538	519	553	559	928
Total Hours	970	983	1011	1005	1014	1009	974	973	1049	1060
Technicians Req'd Per Shift	7.1	7.2	7.4	7.4	7.5	7.4	7.2	7.2	7.7	7.8
Ranking 10 & down	9.7	9.5	9.3	9.3	9.3	9.3	9.6	9.6	8.9	8.9

3A Ranked Best For Smallest Facility

SSTO

7h. Facilities- (Qualitative evaluation) - The candidate vehicle options are compared by the relative size, number, and complexity of operations facilities required.





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Facilities - Horiz. Proc.

Processing Facilities

Assumptions

1) Facility size based on:
   a) Vehicle Dimensions
   b) Constant values for work stands, access, cranes, etc.
2) Number of facilities required is independent of vehicle size
3) Horizontal facility trade therefore based on vehicle dimensions (square feet) only

Horizontal Processing Facility(s)

Configuration	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3
Width	107.5	108.4	108.5	109.4	110.2	108.8	109.0	110.2	112.1	107.9	109.3	108.2
Length	186.9	188.5	188.7	190.3	191.7	181.9	182.3	184.4	187.6	175.4	177.6	176.0
Square Feet	20087	20434	20469	20828	21115	19786	19866	20322	21036	18918	19408	19046
Alternate Rank	9.4	9.3	9.2	9.1	9.0	9.6	9.5	9.3	9.0	10.0	9.7	9.9

Configuration	4A-1	4A-2	1A-1 - Int-Opt10	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - Tl-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
Width	110.2	112.0	107.3	111.4	108.8	110.5	109.2	112.3	109.4	108.6	109.4	111.4	113.7
Length	189.5	192.7	186.7	186.3	182.1	184.9	182.6	188.0	183.0	181.7	183.0	186.4	190.2
Square Feet	20877	21572	20038	20747	19817	20440	19937	21116	20007	19734	20007	20775	21628
Alternate Rank	9.1	8.8	9.4	9.1	9.5	9.3	9.5	9.0	9.5	9.6	9.5	9.1	8.7

Facilities - Horiz. Proc.

Shops (Engine)
Assumptions
1) Same number of engines for all configurations
2) Same maintenance required for engines on all vehicles
3) Therefore, size/cost of engine shop is not a factor in the processing facility trade

Shops (TPS)
Assumptions
1) Based on TPS required for each vehicle configuration
2) Includes area for TPS fabrication (Production Units for tile, blankets)
3) Includes material storage areas
4) AETB Area same for all configurations ==> AETB TPS Shop area same for all configurations
5) Number of blanket replacements varies [redacted] little
Therefore, it is assumed that the ~size of the Blanket TPS Shop area is the same for all configurations

Additional CSic

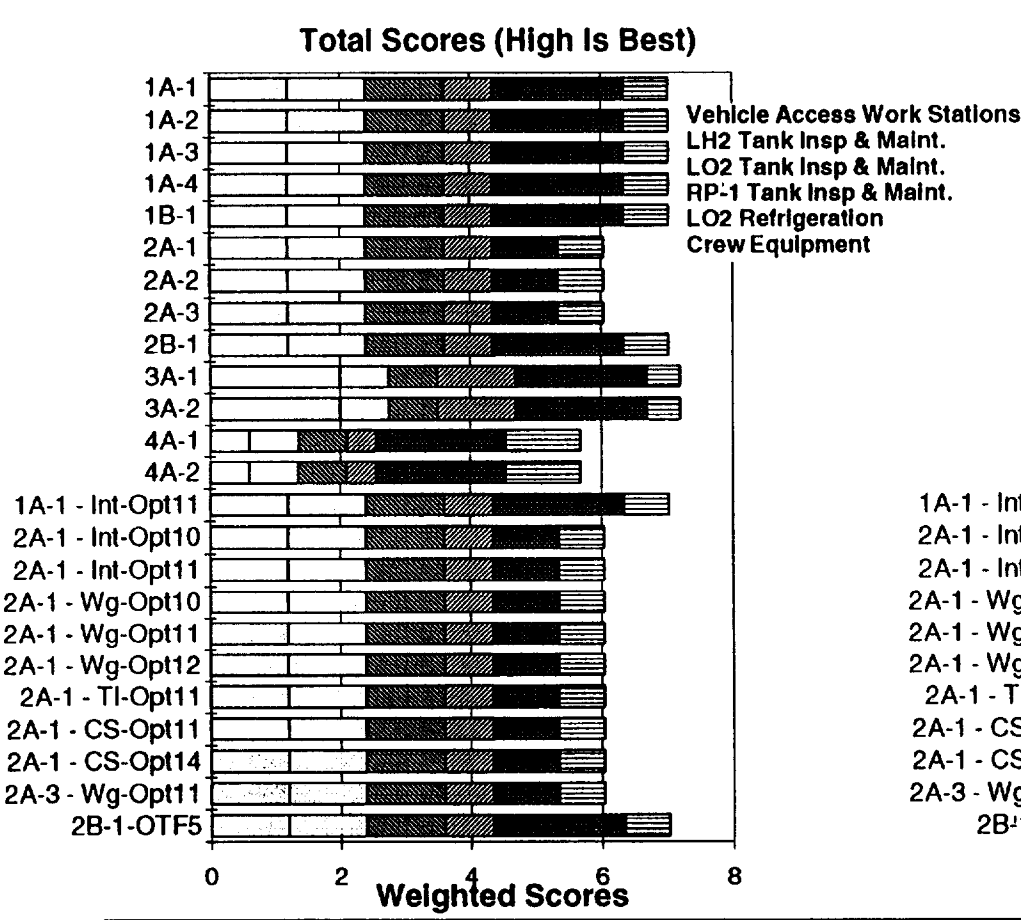
Configuration	1A-1	1A-2	1A-3	1A-4	1B-1	2A-1	2A-2	2A-3	2B-1	3A-1	3A-2	3A-3
Height												
Width												
Length												
Square Feet												
Rank	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

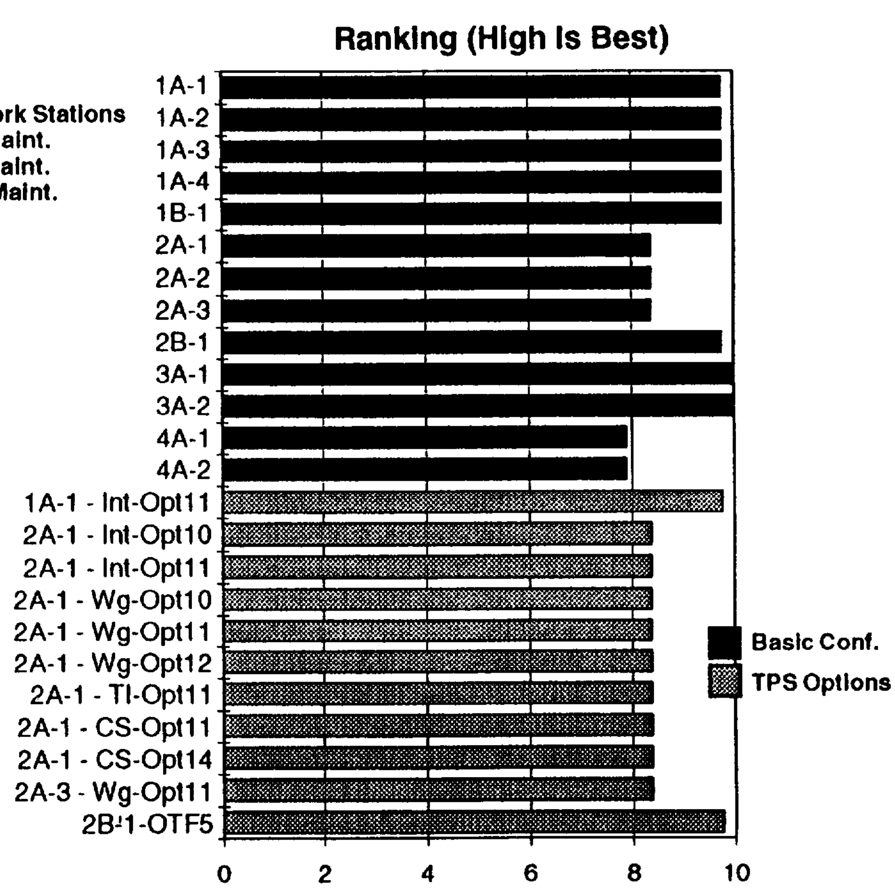
Configuration	4A-1	4A-2	1A-1 - Int-Opt10	2A-1 - Int-Opt10	2A-1 - Int-Opt11	2A-1 - Wg-Opt10	2A-1 - Wg-Opt11	2A-1 - Wg-Opt12	2A-1 - Tl-Opt11	2A-1 - CS-Opt11	2A-1 - CS-Opt14	2A-3 - Wg-Opt11	2B-1-OTF5
Height				7308.8		2773.6		1838.8			540.6		4915.1
Width													
Length													
Square Feet				730.9		277.4		183.9			54.1		491.5
Rank	10.0	10.0	10.0	1.0	10.0	6.6	10.0	7.7	10.0	10.0	9.3	10.0	3.9

1A And 3A Option Ranked Best For Equipment Requirements

SSTO

7i. Equipment requirements - (Qualitative evaluation)- The candidate vehicle options are compared on the basis of unique or additional equipment requirements to perform the maintenance operations from a to h.





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Summary - Equipment Requirements

Configuration		1A-1		1A-2		1A-3		1A-4		1B-1		2A-1		2A-2		2A-3		2B
Selection Criteria	Wt	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score
SLF																		
Safing																		
Vehicle Power/Control		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
RP-1 Removal/Drain Residue GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Emergency																		
Crash Truck		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Fire Truck & Fire Fighting GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Emergency Crew Recovery	2%	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0
Vehicle Recovery GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Vehicle Removal GSE		5.0		5.0		5.0		5.0		5.0		5.0		5.0		5.0		5.0
Tire Pneumatic/Change GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Crew Egress GSE	2%	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0
Horizontal Maintenance Facility																		
TPS GSE - Inspection & Maintenance		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Vehicle Access Work Stations	20%	6.0	1.2	6.0	1.2	6.0	1.2	6.0	1.2	6.0	1.2	6.0	1.2	6.0	1.2	6.0	1.2	6.0
Test/Repair Procedures GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Part/Logistics Identification GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
MPS GSE Inspection GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Avionics Remove & Replace		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Computer GSE for Vehicle TPS Fabrication		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
LH2 Tank Inspection & Maint.. GSE	15%	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0
LO2 Tank Inspection & Maint.. GSE	15%	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0
RP-1 Tank Inspection & Maint.. GSE	15%	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	5.0
P/L Bay GSE - Inspection, Repair & configuration		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Payload Installation GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Structures GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Communications/Telemetry GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Telecommunications GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Environmental System GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Landing Gear & Brake GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Avionics/Electrical Bench Repair & Test GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Ground Power		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Cranes (High and Low Capability)		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
OMS GSE - Inspection & Maint..		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
RCS GSE - Inspection & Maint..		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Electrical GSE - Inspection & Maint..		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Toxic Gas & Liquid Removal GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
SCAPE GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
SSTO Tow Truck (From SLF to HPF)																		
SSTO Tow Truck (From HMF to Pad)																		
Pad																		
LH2 GSE Storage, Loading & Drain		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
LO2 GSE Storage, Loading & Drain		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
LO2 Refrigeration GSE	20%	10.0	2.0	10.0	2.0	10.0	2.0	10.0	2.0	10.0	2.0	5.0	1.0	5.0	1.0	5.0	1.0	10.0
Anti-Geysering GSE		10.0		10.0		10.0		10.0		10.0		1.0		1.0		1.0		1.0

Summary - Equipment Requirements

Configuration	I-1		3A-1		3A-2		3A-3		4A-1		4A-2		1A-1 - Int-Opt11		2A-1 - Int-Opt10		2A-1 - Int-Opt11	
Selection Criteria	Wt	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
SLF																		
Safing																		
Vehicle Power/Control			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
RP-1 Removal/Drain Residue GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Emergency																		
Crash Truck			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Fire Truck & Fire Fighting GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Emergency Crew Recovery	2%	0.1	10.0	0.2	10.0	0.2	10.0	0.2	1.0	0.0	1.0	0.0	5.0	0.1	5.0	0.1	5.0	0.1
Vehicle Recovery GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Vehicle Removal GSE			5.0		5.0		5.0		5.0		5.0		5.0		5.0		5.0	
Tire Pneumatic/Change GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Crew Egress GSE	2%	0.1	10.0	0.2	10.0	0.2	10.0	0.2	1.0	0.0	1.0	0.0	5.0	0.1	5.0	0.1	5.0	0.1
Horizontal Maintenance Facility																		
TPS GSE - Inspection & Maintenance			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Vehicle Access Work Stations	20%	1.2	10.0	2.0	10.0	2.0	10.0	2.0	3.0	0.6	3.0	0.6	6.0	1.2	6.0	1.2	6.0	1.2
Test/Repair Procedures GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Part/Logisitcs Identification GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
MPS GSE Inspection GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Avionics Remove & Replace			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Computer GSE for Vehicle TPS Fabrication			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
LH2 Tank Inspection & Maint.. GSE	15%	1.2	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	8.0	1.2	8.0	1.2	8.0	1.2
LO2 Tank Inspection & Maint.. GSE	15%	1.2	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	8.0	1.2	8.0	1.2	8.0	1.2
RP-1 Tank Inspection & Maint.. GSE	15%	0.8	8.0	1.2	8.0	1.2	8.0	1.2	3.0	0.5	3.0	0.5	5.0	0.8	5.0	0.8	5.0	0.8
P/L Bay GSE - Inspection, Repair & configuration			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Payload Installation GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Structures GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Communications/Telemetry GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Telecommunications GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Environmental System GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Landing Gear & Brake GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Avionics/Electrical Bench Repair & Test GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Ground Power			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Cranes (High and Low Capability)			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
OMS GSE - Inspection & Maint..			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
RCS GSE - Inspection & Maint..			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Electrical GSE - Inspection & Maint..			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Toxic Gas & Liquid Removal GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
SCAPE GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
SSTO Tow Truck (From SLF to HPF)																		
SSTO Tow Truck (From HMF to Pad)																		
Pad																		
LH2 GSE Storage, Loading & Drain			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
LO2 GSE Storage, Loading & Drain			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
LO2 Refrigeration GSE	20%	2.0	10.0	2.0	10.0	2.0	10.0	2.0	10.0	2.0	10.0	2.0	10.0	2.0	5.0	1.0	5.0	1.0
Anit-Geysering GSE			10.0		10.0		10.0		1.0		1.0		10.0		1.0		1.0	

Summary - Equipment Requirements

Configuration		2A-1 - Wg-Opt10		2A-1 - Wg-Opt11		2A-1 - Wg-Opt12		2A-1 - Tl-Opt11		2A-1 - CS-Opt11		2A-1 - CS-Opt14		2A-3 - Wg-Opt11		2B-1-OTF5	
Selection Criteria	Wt	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
SLF																	
Safing																	
Vehicle Power/Control		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
RP-1 Removal/Drain Residue GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Emergency																	
Crash Truck		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Fire Truck & Fire Fighting GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Emergency Crew Recovery	2%	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1
Vehicle Recovery GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Vehicle Removal GSE		5.0		5.0		5.0		5.0		5.0		5.0		5.0		5.0	
Tire Pneumatic/Change GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Crew Egress GSE	2%	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1	5.0	0.1
Horizontal Maintenance Facility																	
TPS GSE - Inspection & Maintenance		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Vehicle Access Work Stations	20%	6.0	1.2	6.0	1.2	6.0	1.2	6.0	1.2	6.0	1.2	6.0	1.2	6.0	1.2	6.0	1.2
Test/Repair Procedures GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Part/Logistics Identification GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
MPS GSE Inspection GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Avionics Remove & Replace		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Computer GSE for Vehicle TPS Fabrication		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
LH2 Tank Inspection & Maint.. GSE	15%	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2
LO2 Tank Inspection & Maint.. GSE	15%	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2	8.0	1.2
RP-1 Tank Inspection & Maint.. GSE	15%	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8	5.0	0.8
P/L Bay GSE - Inspection, Repair & configuration		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Payload Installation GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Structures GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Communications/Telemetry GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Telecommunications GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Environmental System GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Landing Gear & Brake GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Avionics/Electrical Bench Repair & Test GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Ground Power		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Cranes (High and Low Capability)		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
OMS GSE - Inspection & Maint..		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
RCS GSE - Inspection & Maint..		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Electrical GSE - Inspection & Maint..		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Toxic Gas & Liquid Removal GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
SCAPE GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
SSTO Tow Truck (From SLF to HPF)																	
SSTO Tow Truck (From HMF to Pad)																	
Pad																	
LH2 GSE Storage, Loading & Drain		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
LO2 GSE Storage, Loading & Drain		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
LO2 Refrigeration GSE	20%	5.0	1.0	5.0	1.0	5.0	1.0	5.0	1.0	5.0	1.0	5.0	1.0	5.0	1.0	10.0	2.0
Anti-Geysering GSE		1.0		1.0		1.0		1.0		1.0		1.0		1.0		1.0	

Summary - Equipment Requirements

Configuration		1A-1		1A-2		1A-3		1A-4		1B-1		2A-1		2A-2		2A-3		2B
Selection Criteria	Wt	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score
RP=1 GSE Storage, Loading & Drain		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Gas Purge Systems		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
SSTO-to-Pad Mate GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Crew Ingress GSE	5%	5.0	0.3	5.0	0.3	5.0	0.3	5.0	0.3	5.0	0.3	5.0	0.3	5.0	0.3	5.0	0.3	5.0
Lighting GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Crew Emergency Egress GSE	3%	5.0	0.2	5.0	0.2	5.0	0.2	5.0	0.2	5.0	0.2	5.0	0.2	5.0	0.2	5.0	0.2	5.0
Emergency																		
Fire Truck, Fire Fighting GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Crew Removal/Recovery GSE	3%	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0
Vehicle Removal GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
SCAPE GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Launch & Mission Control Center																		
Ground Test, Control & Monitoring GSE (FR Rx & Transit)		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0
Total Wt'd Score	100%		7.0		7.0		7.0		7.0		7.0		6.0		6.0		6.0	

Summary - Equipment Requirements

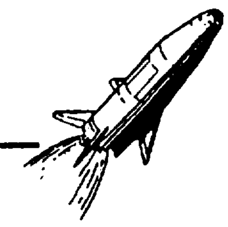
Configuration	I-1		3A-1		3A-2		3A-3		4A-1		4A-2		1A-1 - Int-Opt11		2A-1 - Int-Opt10		2A-1 - Int-Opt11	
Selection Criteria	Wt	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
RP=1 GSE Storage, Loading & Drain			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Gas Purge Systems			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
SSTO-to-Pad Mate GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Crew Ingress GSE	5%	0.3	1.0	0.1	1.0	0.1	1.0	0.1	10.0	0.5	10.0	0.5	5.0	0.3	5.0	0.3	5.0	0.3
Lighting GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Crew Emergency Egress GSE	3%	0.2	1.0	0.0	1.0	0.0	1.0	0.0	10.0	0.3	10.0	0.3	5.0	0.2	5.0	0.2	5.0	0.2
Emergency																		
Fire Truck, Fire Fighting GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Crew Removal/Recovery GSE	3%	0.1	1.0	0.0	1.0	0.0	1.0	0.0	10.0	0.3	10.0	0.3	3.0	0.1	3.0	0.1	3.0	0.1
Vehicle Removal GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
SCAPE GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Launch & Mission Control Center																		
Ground Test, Control & Monitoring GSE			10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
(FR Rx & Transit)																		
Total Wt'd Score	100%	7.0		7.2		7.2		7.2		5.7		5.7		7.0		6.0		6.0

Summary - Equipment Requirements

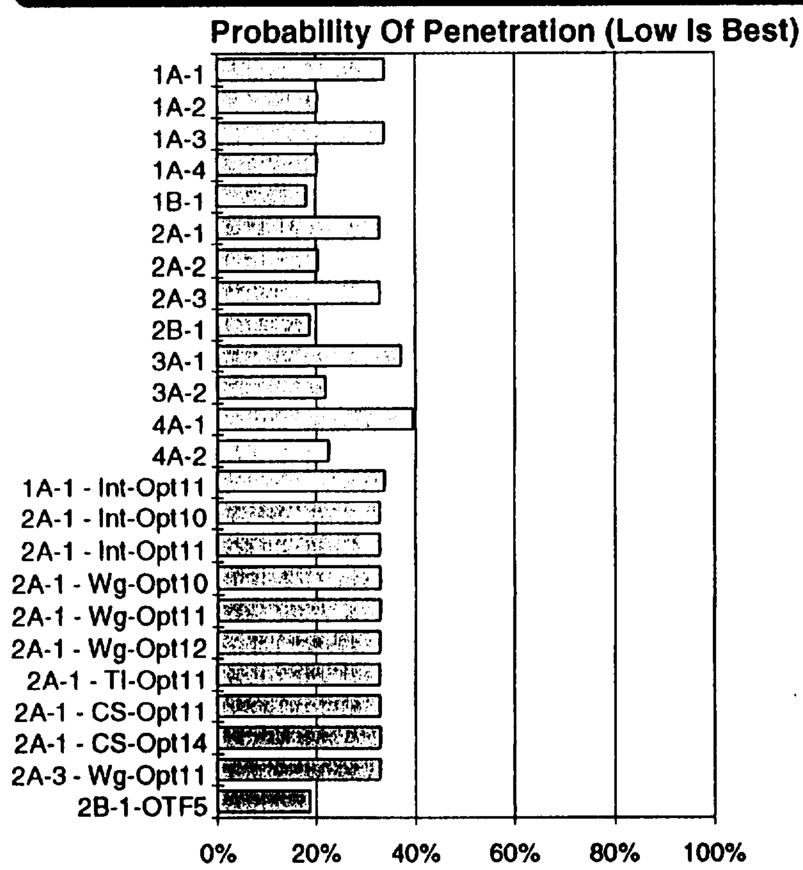
Configuration		2A-1 - Wg-Opt10		2A-1 - Wg-Opt11		2A-1 - Wg-Opt12		2A-1 - Tl-Opt11		2A-1 - CS-Opt11		2A-1 - CS-Opt14		2A-3 - Wg-Opt11		2B-1-OTF5	
Selection Criteria	Wt	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd	Score	Wt'd
RP=1 GSE Storage, Loading & Drain		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Gas Purge Systems		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
SSTO-to-Pad Mate GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Crew Ingress GSE	5%	5.0	0.3	5.0	0.3	5.0	0.3	5.0	0.3	5.0	0.3	5.0	0.3	5.0	0.3	5.0	0.3
Lighting GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Crew Emergency Egress GSE	3%	5.0	0.2	5.0	0.2	5.0	0.2	5.0	0.2	5.0	0.2	5.0	0.2	5.0	0.2	5.0	0.2
Emergency																	
Fire Truck, Fire Fighting GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Crew Removal/Recovery GSE	3%	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1
Vehicle Removal GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
SCAPE GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
Launch & Mission Control Center																	
Ground Test, Control & Monitoring GSE		10.0		10.0		10.0		10.0		10.0		10.0		10.0		10.0	
(FR Rx & Transit)																	
Total Wt'd Score	100%		6.0		6.0		6.0		6.0		6.0		6.0		6.0		7.0

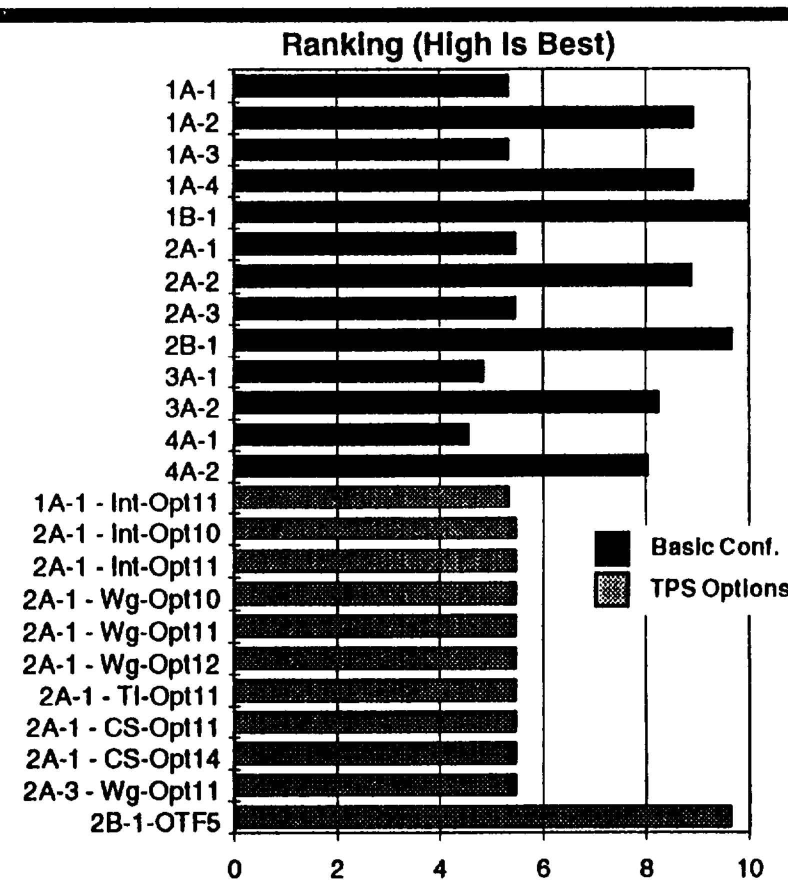
Sandwich Designs Are Ranked Best - Lowest Probability Of Tank Penetration

SSTO



8a. Probability of tank penetration- (Quantitative Analysis) - The candidate vehicle options are compared on the analysis prediction (based on test data) of the probability of cryogenic tank penetration (leakage) for vehicle on-orbit duration's of 90 days.





NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Non-Integral and Sandwich Construction are Best For Debris & Micrometeoroid Probability of No Penetration

SSTO

SC - 8a Probability of Penetration

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	LH2 Tank Bottom Debris Probability of No Penetration	LH2 Tank Top Debris Probability of No Penetration	LOx Tank Bottom Debris Probability of No Penetration	LOx Tank Top Debris Probability of No Penetration	LH2 Tank Bottom Micrometeoroid Probability of No Penetration	LH2 Tank Top Micrometeoroid Probability of No Penetration	LOx Tank Bottom Micrometeoroid Probability of No Penetration	LOx Tank Top Micrometeoroid Probability of No Penetration	Overall Probability of No Penetration
1A-1	0.878576	0.879988	0.967886	0.955917	0.994465	0.959218	0.985432	0.985432	0.662614
1A-2	0.937806	0.954210	0.967886	0.955917	0.998216	0.994465	0.985432	0.985432	0.798121
1A-3	0.878576	0.879988	0.967886	0.955917	0.994465	0.959218	0.985432	0.985432	0.662614
1A-4	0.937806	0.954210	0.967886	0.955917	0.998216	0.994465	0.985432	0.985432	0.798121
1B-1	0.937806	0.977019	0.955375	0.955917	0.998216	0.998216	0.998046	0.985432	0.820042
2A-1	0.933526	0.909446	0.928805	0.929656	0.969570	0.969570	0.996840	0.976539	0.670847
2A-2	0.987569	0.965799	0.928805	0.929656	0.998676	0.995889	0.996840	0.976539	0.797355
2A-3	0.933526	0.909446	0.928805	0.929656	0.969570	0.969570	0.996840	0.976539	0.670847
2B-1	0.987569	0.982887	0.928805	0.929656	0.998676	0.998676	0.996840	0.976539	0.813733
3A-1	0.859239	0.860858	0.967886	0.955917	0.993518	0.952388	0.985432	0.985432	0.628829
3A-2	0.927510	0.946553	0.967886	0.955917	0.997910	0.993518	0.985432	0.985432	0.782039
3A-3	0.927510	0.946553	0.967886	0.955917	0.997910	0.993518	0.985432	0.985432	0.782039
4A-1	0.841219	0.843025	0.960373	0.960855	0.992616	0.945923	0.998270	0.987095	0.605468
4A-2	0.917810	0.939316	0.960373	0.960855	0.997619	0.992616	0.998270	0.987095	0.776274
1A-1-Int-Opt 10	0.878576	0.879988	0.967886	0.955917	0.994465	0.959218	0.985432	0.985432	0.662614
2A-1-Int-Opt 10	0.933526	0.909446	0.928805	0.929656	0.969570	0.969570	0.996840	0.976539	0.670847
2A-1-Int-Opt 11	0.933526	0.909446	0.928805	0.929656	0.969570	0.969570	0.996840	0.976539	0.670847
2A-1-Wing-Opt 10	0.933526	0.909446	0.928805	0.929656	0.969570	0.969570	0.996840	0.976539	0.670847
2A-1-Wing-Opt 11	0.933526	0.909446	0.928805	0.929656	0.969570	0.969570	0.996840	0.976539	0.670847
2A-1-Wing-Opt 12	0.933526	0.909446	0.928805	0.929656	0.969570	0.969570	0.996840	0.976539	0.670847
2A-1-Tail-Opt 11	0.933526	0.909446	0.928805	0.929656	0.969570	0.969570	0.996840	0.976539	0.670847
2A-1-CS-Opt 11	0.933526	0.909446	0.928805	0.929656	0.969570	0.969570	0.996840	0.976539	0.670847
2A-1-CS-Opt 14	0.933526	0.909446	0.928805	0.929656	0.969570	0.969570	0.996840	0.976539	0.670847
2A-3-Wing-Opt 11	0.933526	0.909446	0.928805	0.929656	0.969570	0.969570	0.996840	0.976539	0.670847
2B-1-OTF6	0.987569	0.982887	0.928805	0.929656	0.998243	0.998243	0.996840	0.976539	0.813028

Debris Impact Tests Completed

All Panels Tested at NASA/MSFC During Phase 1 and Delta Tests

Test Id	Date Tested	Panel	TPS		Foam		Particle		Panel		Nextel	Composite Panel
		Sample Id	Type	Thickness	Type	Thickness	Size	Thickness	Material	Type	Bumper	Damage From Test
1634	1/19/95	A1	FRSI	0.16 - N - 0.32	51WF	0.75	0.187	0.090	IM7/8552	Skin/Stringer	Yes	0.60 by 1.07 inch Hole
1641	1/24/95	A2	FRSI	0.16 - N - 0.32	51WF	0.75	0.125	0.090	IM7/8552	Skin/Stringer	Yes	None Visible
1650	1/31/95	10	FRSI	0.16 - N - 0.32 - K	51WF	0.50	0.187	0.090	IM7/8552	Skin/Stringer	Yes & Kevlar	0.82 by 1.30 inch Hole
1652	2/1/95	11	FRSI	0.16 - N - 0.32 - K	51WF	0.50	0.250	0.090	IM7/8552	Skin/Stringer	Yes & Kevlar	1.32 by 1.54 inch Hole
1653	2/1/95	12	FRSI	0.32 - N - 0.32 - K	51WF	0.50	0.187	0.090	IM7/8552	Skin/Stringer	Yes & Kevlar	0.40 by 0.54 inch Hole
1656	2/6/95	13	FRSI	0.32 - N - 0.32 - K	51WF	0.50	0.187	0.090	IM7/8552	Skin/Stringer	Yes & Kevlar	0.77 by 0.9 inch Hole
1668	2/14/95	26	FRSI	0.16 - N - 0.32	71WF	0.75	0.187	0.090	IM7/8552	Skin/Stringer	Yes	0.68 by 1.26 inch Hole
1670	2/14/95	25	FRSI	0.16 - N - 0.32	71WF	0.75	0.125	0.090	IM7/8552	Skin/Stringer	Yes	Delamination with No Penetration
1635	1/19/95	A3	AFRSI	N - 0.75	51WF	0.75	0.187	0.090	IM7/8552	Skin/Stringer	Yes	0.70 by 1.40 inch Hole
1637	1/20/95	A4	AFRSI	N - 0.75 - N	51WF	0.75	0.187	0.090	IM7/8552	Skin/Stringer	Yes	0.67 by 1.13 inch Hole
1654	2/1/95	14	AFRSI	N - 1.0 - K	51WF	0.50	0.187	0.090	IM7/8552	Skin/Stringer	Yes Coated & Kevlar	0.75 by 1.26 inch Hole
1655	2/1/95	18	AFRSI	N (C9 Coating) - 1.0 - K	51WF	0.50	0.187	0.090	IM7/8552	Skin/Stringer	Yes Coated & Kevlar	0.60 by 0.67 inch Hole
1657	2/6/95	20	AFRSI	N (C9 Coating) - 1.0 - K	51WF	0.75	0.187	0.090	IM7/8552	Skin/Stringer	Yes Coated & Kevlar	0.60 by 1.10 inch Hole
1658	2/6/95	21	AFRSI	N (C9 Coating) - 1.0 - K	51WF	0.75	0.187	0.090	IM7/8552	Skin/Stringer	Yes Coated & Kevlar	0.55 by 0.80 inch Hole
1665	2/10/95	17	AFRSI	N - 2.0 - K	51WF	0.75	0.250	0.090	IM7/8552	Skin/Stringer	Yes & Kevlar	2.68 by 1.39 inch Hole
1667	2/13/95	16	AFRSI	N - 2.0 - K	51WF	0.75	0.187	0.090	IM7/8552	Skin/Stringer	Yes & Kevlar	None Visible
1672	2/15/95	15	AFRSI	N - 1.0 - K	51WF	0.50	0.187	0.090	IM7/8552	Skin/Stringer	Yes & Kevlar	1.30 by 0.80 inch Hole
1673	2/15/95	19	AFRSI	N (C9 Coating) - 1.0 - K	51WF	0.50	0.187	0.090	IM7/8552	Skin/Stringer	Yes Coated & Kevlar	0.40 by 0.70 inch Hole
1642	1/25/95	A6	AFRSI	1.00	51WF	0.75	0.125	0.045 Facesheet	IM7/8552	Honeycomb	No	None Visible
1643	1/25/95	A7	AFRSI	2.00	51WF	0.75	0.125	0.045 Facesheet	IM7/8552	Honeycomb	No	None Visible
1671	2/14/95	28	AFRSI	1.00	51WF	0.50	0.187	0.045 Facesheet	IM7/8552	Honeycomb	No	0.98 by 0.87 inch Hole
1659	2/7/95	4	Non-Integral Tank FRSI	0.16 - 0.32	51WF	0.75	0.125	0.090	IM7/8552	Non-Integral	No	None Visible
1660	2/7/95	5	Non-Integral Tank FRSI	0.16 - 0.32	51WF	0.75	0.187	0.090	IM7/8552	Non-Integral	No	None Visible
1662	2/9/95	8	Non-Integral Tank AETB	2.00	51WF	0.75	0.250	0.090	IM7/8552	Non-Integral	No	None Visible
1664	2/10/95	9	Non-Integral Tank AETB	2.00	51WF	0.75	0.313	0.090	IM7/8552	Non-Integral	No	None Visible
1661	2/9/95	6	Non-Integral Tank AFRSI	0.75	51WF	0.75	0.187	0.090	IM7/8552	Non-Integral	No	None Visible
1663	2/10/95	7	Non-Integral Tank AFRSI	0.75	51WF	0.75	0.250	0.090	IM7/8552	Non-Integral	No	.07 Inch Diameter Hole
1603	9/19/94	10	AFRSI	0.50	51WF	0.50	0.125, 0°	0.099	IM7/8552	Skin/Stringer	No	0.45 by 0.24 Inch Hole
1604	9/20/94	13	AFRSI	0.50	51WF	0.50	0.125, 0°	0.099	IM7/8552	Skin/Stringer	Yes	Small Amount of Delamination Rear Side
1605	9/20/94	16	AFRSI	1.00	51WF	0.75	0.125, 0°	0.099	IM7/8552	Skin/Stringer	No	None Visible
1606	9/20/94	17	AFRSI	1.00	51WF	0.75	0.250, 0°	0.097	IM7/8552	Skin/Stringer	No	1.25 by 2.20 Inch Hole
1607	9/21/94		AFRSI	1.00	51WF	0.75	0.187, 0°	0.097	IM7/8552	Skin/Stringer	No	1.0 by 0.50 Inch Hole
1608	9/21/94		AFRSI	0.50 (Taped)	51WF	0.50	0.125, 0°	0.098	IM7/8552	Skin/Stringer	No	0.40 by 0.23 Inch Hole
1609	9/22/94		AFRSI	0.50	51WF	0.50	0.187, 0°	0.095	IM7/8552	Skin/Stringer	Yes	0.90 by 0.90 Inch Hole
1610	9/22/94		AFRSI	0.50	51WF	0.50	0.187, 30°	0.094	IM7/8552	Skin/Stringer	Yes	1.1 by 0.80 Inch Hole
1611	9/23/94		AFRSI	0.50	51WF	0.50	0.125, 30°	0.096	IM7/8552	Skin/Stringer	No	Bad Shot
1612	9/28/94		FRSI	0.35	51WF	0.80	0.125	0.096	IM7/8552	Skin/Stringer	No	0.60 by 0.30 Inch Hole
1613	9/28/94		FRSI	0.50	51WF	0.50	0.125	0.096	IM7/8552	Skin/Stringer	No	Circular Hole 0.4 Inch Diameter, Delamination
1615	9/28/94		FRSI	0.50	51WF	0.50	0.125	0.096	IM7/8552	Skin/Stringer	Yes	No Penetration, Delamination 0.5 by 7 Inch
1616	10/6/94		AETB	2.00	51WF	0.70	0.125	0.096	IM7/8552	Skin/Stringer	No	None Visible
1617	10/6/94		AETB	2.00	51WF	0.70	0.250	0.096	IM7/8552	Skin/Stringer	No	None Visible
1618	10/7/94		AETB	2.50	51WF	1.00	0.250	0.096	IM7/8552	Skin/Stringer	No	None Visible
1619	10/7/94		AETB	2.50	51WF	1.00	0.375	0.096	IM7/8552	Skin/Stringer	No	2.5 by 5.5 Inch Hole
1620	10/7/94		AETB	2.50	51WF	1.00	0.313	0.096	IM7/8552	Skin/Stringer	No	0.3 by 0.4 Hole, Delamination on Rear Side
1621	10/11/94		AETB	2.00	51WF	0.70	0.313	0.096	IM7/8552	Skin/Stringer	No	1.5 by 3.0 Hole, Panel Delamination on Rear Side
1625	10/13/94		AETB	3.00	51WF	1.20	0.313	0.096	IM7/8552	Skin/Stringer	No	None Visible
1626	10/21/94		AETB	3.00	51WF	1.20	0.375	0.096	IM7/8552	Skin/Stringer	No	Severely Delaminated and Torn into many pieces
1624	10/12/94		Non-Integral Tank FRSI	0.36	51WF	0.70	0.250	0.100	IM7/8552	Skin/Stringer	No	1.7 Inch Irregular Shaped Hole
1630	12/29/94		Non-Integral Tank FRSI	0.28	51WF	0.70	0.187	0.096	IM7/8552	Skin/Stringer	No	None Visible
1622	10/12/94		Non-Integral Tank AETB	0.50	51WF	0.50	0.375	0.096	IM7/8552	Skin/Stringer	No	2.5 by 1.3 Inch Hole
1623	10/12/94		Non-Integral Tank AETB	0.50	51WF	0.50	0.313	0.096	IM7/8552	Skin/Stringer	No	0.4 Inch Diameter Hole
1631	12/29/94		Non-Integral Tank AFRSI	0.25	51WF	0.70	0.187	0.096	IM7/8552	Skin/Stringer	No	None Visible
1632	12/29/94		Non-Integral Tank AFRSI	0.50	51WF	0.60	0.250	0.096	IM7/8552	Skin/Stringer	No	0.4 by 0.2 Inch Hole

SC - 8a Probability of Penetration

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	LH2 Tank Bottom Debris Probability of No Penetration	LH2 Tank Top Debris Probability of No Penetration	LOx Tank Botttom Debris Probability of No Penetration	LOx Tank Top Debris Probability of No Penetration	LH2 Tank Bottom Micrometeoroid Probability of No Penetration	LH2 Tank Top Micrometeoroid Probability of No Penetration	LOx Tank Botttom Micrometeoroid Probability of No Penetration	LOx Tank Top Micrometeoroid Probability of No Penetration	Overall Probability of No Penetration
1A-1	0.878576	0.879988	0.967886	0.955917	0.994465	0.959218	0.985432	0.985432	0.662614
1A-2	0.937806	0.95421	0.967886	0.955917	0.998216	0.994465	0.985432	0.985432	0.798121
1A-3	0.878576	0.879988	0.967886	0.955917	0.994465	0.959218	0.985432	0.985432	0.662614
1A-4	0.937806	0.95421	0.967886	0.955917	0.998216	0.994465	0.985432	0.985432	0.798121
1B-1	0.937806	0.977019	0.955375	0.955917	0.998216	0.998216	0.998046	0.985432	0.820042
2A-1	0.933526	0.909446	0.928805	0.929656	0.96957	0.96957	0.99684	0.976539	0.670847
2A-2	0.987569	0.965799	0.928805	0.929656	0.998676	0.995889	0.99684	0.976539	0.797355
2A-3	0.933526	0.909446	0.928805	0.929656	0.96957	0.96957	0.99684	0.976539	0.670847
2B-1	0.987569	0.982887	0.928805	0.929656	0.998676	0.998676	0.99684	0.976539	0.813733
3A-1	0.859239	0.860858	0.967886	0.955917	0.993518	0.952388	0.985432	0.985432	0.628829
3A-2	0.92751	0.946553	0.967886	0.955917	0.99791	0.993518	0.985432	0.985432	0.782039
3A-3	0.92751	0.946553	0.967886	0.955917	0.99791	0.993518	0.985432	0.985432	0.782039
4A-1	0.841219	0.843025	0.960373	0.960855	0.992616	0.945923	0.99827	0.987095	0.605468
4A-2	0.91781	0.939316	0.960373	0.960855	0.997619	0.992616	0.99827	0.987095	0.776274
1A-1-Int-Opt 10	0.878576	0.879988	0.967886	0.955917	0.994465	0.959218	0.985432	0.985432	0.662614
2A-1-Int-Opt 10	0.933526	0.909446	0.928805	0.929656	0.96957	0.96957	0.99684	0.976539	0.670847
2A-1-Int-Opt 11	0.933526	0.909446	0.928805	0.929656	0.96957	0.96957	0.99684	0.976539	0.670847
2A-1-Wing-Opt 10	0.933526	0.909446	0.928805	0.929656	0.96957	0.96957	0.99684	0.976539	0.670847
2A-1-Wing-Opt 11	0.933526	0.909446	0.928805	0.929656	0.96957	0.96957	0.99684	0.976539	0.670847
2A-1-Wing-Opt 12	0.933526	0.909446	0.928805	0.929656	0.96957	0.96957	0.99684	0.976539	0.670847
2A-1-Tail-Opt 11	0.933526	0.909446	0.928805	0.929656	0.96957	0.96957	0.99684	0.976539	0.670847
2A-1-CS-Opt 11	0.933526	0.909446	0.928805	0.929656	0.96957	0.96957	0.99684	0.976539	0.670847
2A-1-CS-Opt 14	0.933526	0.909446	0.928805	0.929656	0.96957	0.96957	0.99684	0.976539	0.670847
2A-3-Wing-Opt 11	0.933526	0.909446	0.928805	0.929656	0.96957	0.96957	0.99684	0.976539	0.670847
2B-1-OTF5	0.987569	0.982887	0.928805	0.929656	0.998243	0.998243	0.99684	0.976539	0.813028

Probability of No Impact

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

LH Tank — Bottom

Modified 100 Mission MSFC Model For Area Difference

Vehicle Option	Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Probability of No Impact (0.125 Inch)	Probability of No Impact (0.1875 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
1A-1	1.38	AFRSI	0.99	Rohacell	Skin / Stringer	0.702506	0.878576	0.937806	0.963045	0.975693	0.878576	1605	0.125	None Visible
1A-3	1.38	AFRSI	0.99	Rohacell	Skin / Stringer	0.702506	0.878576	0.937806	0.963045	0.975693	0.878576	1605	0.125	None Visible
1A-2	1.74	AFRSI	0.31+1.16	Rohacell	Honeycomb	0.702506	0.878576	0.937806	0.963045	0.975693	0.937806	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
1A-4	1.74	AFRSI	.31+1.16	Rohacell	Honeycomb	0.702506	0.878576	0.937806	0.963045	0.975693	0.937806	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
2A-1	0.50	AFRSI	0.38	Rohacell	Skin / Stringer	0.933826	0.975097	0.987569	0.992691	0.995218	0.933826	1603	0.125	0.45 by 0.24 Inch Hole
2A-3	0.50	AFRSI	0.38	Rohacell	Skin / Stringer	0.933826	0.975097	0.987569	0.992691	0.995218	0.933826	1603	0.125	0.45 by 0.24 Inch Hole
2A-2	0.50	AFRSI	1.50	Rohacell	Honeycomb	0.933826	0.975097	0.987569	0.992691	0.995218	0.987569	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
3A-1	0.76	AFRSI	0.58	Rohacell	Skin / Stringer	0.661130	0.859239	0.927510	0.956831	0.971574	0.859239	1605	0.125	None Visible
3A-2	1.05	AFRSI	.19+1.26	Rohacell	Honeycomb	0.661130	0.859239	0.927510	0.956831	0.971574	0.927510	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
3A-3	1.05	AFRSI	.19+1.26	Rohacell	Honeycomb	0.661130	0.859239	0.927510	0.956831	0.971574	0.927510	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
4A-1	1.12	AFRSI	0.81	Rohacell	Skin / Stringer	0.623992	0.841219	0.917810	0.950950	0.967667	0.841219	1605	0.125	None Visible
4A-2	1.25	AFRSI	0.19+1.16	Rohacell	Honeycomb	0.623992	0.841219	0.917810	0.950950	0.967667	0.917810	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
1B-1	0.55	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.702506	0.878576	0.937806	0.963045	0.975693	0.937806	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better
2B-1	0.50	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.933826	0.975097	0.987569	0.992691	0.996218	0.987569	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better
2B-1-OTF5	0.38	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.933826	0.975097	0.987569	0.990316	0.993798	0.987569	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better

Probability of No Impact

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

LH Tank — Top

Modified 100 Mission MSFC Model For Area Difference

Vehicle Option	Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Probability of No Impact (0.125 Inch)	Probability of No Impact (0.168 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
1A-1	0.47	AFRSI	0.38	Rohacell	Skin / Stringer	0.879988	0.954210	0.977019	0.986459	0.991130	0.879988	1603	0.125	0.45 by 0.24 Inch Hole
1A-3	0.47	AFRSI	0.38	Rohacell	Skin / Stringer	0.879988	0.954210	0.977019	0.986459	0.991130	0.879988	1603	0.125	0.45 by 0.24 Inch Hole
1A-2	0.40	AFRSI	0.00+1.16	Rohacell	Honeycomb	0.879988	0.954210	0.977019	0.986459	0.991130	0.954210	1641	0.125	Test Results For FRSI - AFRSI Assumed to be Better
1A-4	0.40	AFRSI	0.00+1.16	Rohacell	Honeycomb	0.879988	0.954210	0.977019	0.986459	0.991130	0.954210	1641	0.125	Test Results For FRSI - AFRSI Assumed to be Better
2A-1	0.43	AFRSI	0.38	Rohacell	Skin / Stringer	0.909446	0.965799	0.982887	0.989929	0.993407	0.909446	1603	0.125	0.45 by 0.24 Inch Hole
2A-3	0.43	AFRSI	0.38	Rohacell	Skin / Stringer	0.909446	0.965799	0.982887	0.989929	0.993407	0.909446	1603	0.125	0.45 by 0.24 Inch Hole
2A-2	0.40	AFRSI	1.50	Rohacell	Honeycomb	0.909446	0.965799	0.982887	0.989929	0.993407	0.965799	1642	0.125	None Visible
3A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer	0.860858	0.946553	0.973122	0.984149	0.989613	0.860858	1603	0.125	0.45 by 0.24 Inch Hole
3A-2	0.40	AFRSI	0.00+1.26	Rohacell	Honeycomb	0.860858	0.946553	0.973122	0.984149	0.989613	0.946553	1642	0.125	None Visible
3A-3	0.40	AFRSI	0.00+1.26	Rohacell	Honeycomb	0.860858	0.946553	0.973122	0.984149	0.989613'	0.946553	1642	0.125	None Visible
4A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer	0.843025	0.939318	0.969424	0.981955	0.988170	0.843025	1603	0.125	0.45 by 0.24 Inch Hole
4A-2	0.50	AFRSI	0.00+1.16	Rohacell	Honeycomb	0.843025	0.939318	0.969424	0.981955	0.988170	0.939318	1642	0.125	None Visible
1B-1	0.50	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.879988	0.954210	0.977019	0.986459	0.991130	0.977019	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better
2B-1	0.40	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.909446	0.965799	0.982887	0.989929	0.993407	0.982887	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better
2B-1-OTF5	0.38	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.909446	0.965799	0.982887	0.986459	0.991130	0.982887	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better

Probability of No Impact

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area) | Modified 100 Mission MSFC Model For Area Difference | Modified 100 Mission MSFC Model F

Vehicle Option	LOx Tank Bottom Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Probability of No Impact (0.125 Inch)	Probability of No Impact (0.188 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
1A-1	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988105	0.994082	0.996526	0.997728	0.967886	1603	0.125	0.45 by 0.24 Inch Hole
1A-3	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988105	0.994082	0.996526	0.997728	0.967886	1603	0.125	0.45 by 0.24 Inch Hole
1A-2	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988105	0.994082	0.996526	0.997728	0.967886	1603	0.125	0.45 by 0.24 Inch Hole
1A-4	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988105	0.994082	0.996526	0.997728	0.967886	1603	0.125	0.45 by 0.24 Inch Hole
2A-1	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.817541	0.928805	0.964028	0.978746	0.986059	0.928805	1605	0.125	None Visible
2A-3	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.817541	0.928805	0.964028	0.978746	0.986059	0.928805	1605	0.125	None Visible
2A-2	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.817541	0.928805	0.964028	0.978746	0.986059	0.928805	1605	0.125	None Visible
3A-1	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988105	0.994082	0.996526	0.997728	0.967886	1603	0.125	0.45 by 0.24 Inch Hole
3A-2	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988105	0.994082	0.996526	0.997728	0.967886	1603	0.125	0.45 by 0.24 Inch Hole
3A-3	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988105	0.994082	0.996526	0.997728	0.967886	1603	0.125	0.45 by 0.24 Inch Hole
4A-1	0.85	AFRSI	0.53	Rohacell	Skin / Stringer Al-Li	0.895576	0.960373	0.980144	0.988307	0.992343	0.960373	1605	0.125	None Visible
4A-2	0.85	AFRSI	0.53	Rohacell	Skin / Stringer Al-Li	0.895576	0.960373	0.980144	0.988307	0.992343	0.960373	1605	0.125	None Visible
1B-1	0.93	AFRSI	0.67	Rohacell	Skin / Stringer Al-Li	0.967886	0.988105	0.994082	0.996526	0.997728	0.988105	1605	0.125	None Visible
2B-1	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.967886	0.988105	0.994082	0.996526	0.997728	0.988105	1605	0.125	None Visible
2B-1-OTF5	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.946882	0.980826	0.990443	0.994384	0.996327	0.980826	1605	0.125	None Visible

Probability of No Impact

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area) | Modified 100 Mission MSFC Model For Area Difference | Modified 100 Mission MSFC Model F

Vehicle Option	LOx Tank Top Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Probability of No Impact (0.125 Inch)	Probability of No Impact (0.188 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
1A-1	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.955917	1603	0.125	0.45 by 0.24 Inch Hole
1A-3	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.955917	1603	0.125	0.45 by 0.24 Inch Hole
1A-2	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.955917	1603	0.125	0.45 by 0.24 Inch Hole
1A-4	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.955917	1603	0.125	0.45 by 0.24 Inch Hole
2A-1	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.929656	0.973613	0.986823	0.992252	0.994930	0.929656	1603	0.125	0.45 by 0.24 Inch Hole
2A-3	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.929656	0.973613	0.986823	0.992252	0.994930	0.929656	1603	0.125	0.45 by 0.24 Inch Hole
2A-2	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.929656	0.973613	0.986823	0.992252	0.994930	0.929656	1603	0.125	0.45 by 0.24 Inch Hole
3A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.955917	1603	0.125	0.45 by 0.24 Inch Hole
3A-2	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.955917	1603	0.125	0.45 by 0.24 Inch Hole
3A-3	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.955917	1603	0.125	0.45 by 0.24 Inch Hole
4A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.960855	0.985467	0.992765	0.995751	0.997221	0.960855	1603	0.125	0.45 by 0.24 Inch Hole
4A-2	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.960855	0.985467	0.992765	0.995751	0.997221	0.960855	1603	0.125	0.45 by 0.24 Inch Hole
1B-1	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.955917	1603	0.125	0.45 by 0.24 Inch Hole
2B-1	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.929656	0.973613	0.986823	0.992252	0.994930	0.929656	1603	0.125	0.45 by 0.24 Inch Hole
2B-1-OTF5	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.929656	0.973613	0.986823	0.992252	0.994930	0.929656	1603	0.125	0.45 by 0.24 Inch Hole

Probability of No Impact

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	Probability of No Impact (0.125 inch)	Probability of No Impact (0.188 inch)	Probability of No Impact (0.250 inch)	Total Vehicle Probability of No Impact
1A-1	0.571967	0.814794	0.903395	0.715320
1A-3	0.571967	0.814794	0.903395	0.715320
1A-2	0.571967	0.814794	0.903395	0.827945
1A-4	0.571967	0.814794	0.903395	0.827945
2A-1	0.645261	0.851619	0.923421	0.733078
2A-3	0.645261	0.851619	0.923421	0.733078
2A-2	0.645261	0.851619	0.923421	0.823571
3A-1	0.526578	0.790467	0.889913	0.684368
3A-2	0.526578	0.790467	0.889913	0.812284
3A-3	0.526578	0.790467	0.889913	0.812284
4A-1	0.452668	0.747830	0.865771	0.654406
4A-2	0.452668	0.747830	0.865771	0.795541
1B-1	0.571967	0.814794	0.903395	0.865445
2B-1	0.763923	0.905991	0.952210	0.891654
2B-1-OTF5	0.748672	0.899317	0.948724	0.885086

Probability of No Impact

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area) — LH Tank Bottom; Modified 100 Mission MSFC Model For Area Difference

Vehicle Option	Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Probability of No Impact (0.125 Inch)	Probability of No Impact (0.1875 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
1A-1	1.38	AFRSI	0.99	Rohacell	Skin / Stringer	0.959218	0.994465	0.998216	0.999263	0.999643	0.994465	1605	0.125	None Visible
1A-3	1.38	AFRSI	0.99	Rohacell	Skin / Stringer	0.959218	0.994465	0.998216	0.999263	0.999643	0.994465	1605	0.125	None Visible
1A-2	1.74	AFRSI	0.31+1.16	Rohacell	Honeycomb	0.959218	0.994465	0.998216	0.999263	0.999643	0.998216	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
1A-4	1.74	AFRSI	.31+1.16	Rohacell	Honeycomb	0.959218	0.994465	0.998216	0.999263	0.999643	0.998216	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
2A-1	0.50	AFRSI	0.38	Rohacell	Skin / Stringer	0.991924	0.998920	0.999652	0.999856	0.999930	0.991924	1603	0.125	0.45 by 0.24 inch Hole
2A-3	0.50	AFRSI	0.38	Rohacell	Skin / Stringer	0.991924	0.998920	0.999652	0.999856	0.999930	0.991924	1603	0.125	0.45 by 0.24 inch Hole
2A-2	0.50	AFRSI	1.50	Rohacell	Honeycomb	0.991924	0.998920	0.999652	0.999856	0.999930	0.999652	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
3A-1	0.76	AFRSI	0.58	Rohacell	Skin / Stringer	0.952388	0.993518	0.997910	0.999136	0.999581	0.993518	1605	0.125	None Visible
3A-2	1.05	AFRSI	.19+1.26	Rohacell	Honeycomb	0.952388	0.993518	0.997910	0.999136	0.999581	0.997910	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
3A-3	1.05	AFRSI	.19+1.26	Rohacell	Honeycomb	0.952388	0.993518	0.997910	0.999136	0.999581	0.997910	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
4A-1	1.12	AFRSI	0.81	Rohacell	Skin / Stringer	0.945923	0.992616	0.997619	0.999016	0.999523	0.992616	1605	0.125	None Visible
4A-2	1.25	AFRSI	0.19+1.16	Rohacell	Honeycomb	0.945923	0.992616	0.997619	0.999016	0.999523	0.997619	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
1B-1	0.55	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.959218	0.994465	0.998216	0.999263	0.999643	0.998216	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better
2B-1	0.50	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.991924	0.998920	0.999652	0.999856	0.999930	0.999652	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better
2B-1-OTF5	0.38	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.989299	0.998567	0.999539	0.999809	0.999908	0.999539	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better

Probability of No Impact

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area) — LH Tank Top; Modified 100 Mission MSFC Model For Area Difference

Vehicle Option	Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Probability of No Impact (0.125 Inch)	Probability of No Impact (0.188 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
1A-1	0.47	AFRSI	0.38	Rohacell	Skin / Stringer	0.959218	0.994465	0.998216	0.999263	0.999643	0.959218	1603	0.125	0.45 by 0.24 inch Hole
1A-3	0.47	AFRSI	0.38	Rohacell	Skin / Stringer	0.959218	0.994465	0.998216	0.999263	0.999643	0.959218	1603	0.125	0.45 by 0.24 inch Hole
1A-2	0.40	AFRSI	0.00+1.16	Rohacell	Honeycomb	0.959218	0.994465	0.998216	0.999263	0.999643	0.994465	1641	0.125	Test Results For FRSI - AFRSI Assumed to be Better
1A-4	0.40	AFRSI	0.00+1.16	Rohacell	Honeycomb	0.959218	0.994465	0.998216	0.999263	0.999643	0.994465	1641	0.125	Test Results For FRSI - AFRSI Assumed to be Better
2A-1	0.43	AFRSI	0.38	Rohacell	Skin / Stringer	0.989570	0.995889	0.998676	0.999453	0.999735	0.989570	1603	0.125	0.45 by 0.24 inch Hole
2A-3	0.43	AFRSI	0.38	Rohacell	Skin / Stringer	0.989570	0.995889	0.998676	0.999453	0.999735	0.989570	1603	0.125	0.45 by 0.24 inch Hole
2A-2	0.40	AFRSI	1.50	Rohacell	Honeycomb	0.989570	0.995889	0.998676	0.999453	0.999735	0.995889	1642	0.125	None Visible
3A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer	0.952388	0.993518	0.997910	0.999136	0.999581	0.952388	1603	0.125	0.45 by 0.24 inch Hole
3A-2	0.40	AFRSI	0.00+1.26	Rohacell	Honeycomb	0.952388	0.993518	0.997910	0.999136	0.999581	0.993518	1642	0.125	None Visible
3A-3	0.40	AFRSI	0.00+1.26	Rohacell	Honeycomb	0.952388	0.993518	0.997910	0.999136	0.999581	0.993518	1642	0.125	None Visible
4A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer	0.945923	0.992616	0.997619	0.999016	0.999523	0.945923	1603	0.125	0.45 by 0.24 inch Hole
4A-2	0.50	AFRSI	0.00+1.16	Rohacell	Honeycomb	0.945923	0.992616	0.997619	0.999016	0.999523	0.992616	1642	0.125	None Visible
1B-1	0.50	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.959218	0.994465	0.998216	0.999263	0.999643	0.998216	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better
2B-1	0.40	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.989570	0.995889	0.998676	0.999453	0.999735	0.998676	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better
2B-1-OTF5	0.38	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.959218	0.994465	0.998243	0.999266	0.999643	0.998243	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better

Probability of No Impact

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	LOx Tank Bottom Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Modified 100 Mission MSFC Model For Area Difference Probability of No Impact (0.125 Inch)	Probability of No Impact (0.188 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
1A-1	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.996161	0.999487	0.999835	0.999932	0.999967	0.996161	1603	0.125	0.45 by 0.24 inch Hole
1A-3	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.996161	0.999487	0.999835	0.999932	0.999967	0.996161	1603	0.125	0.45 by 0.24 inch Hole
1A-2	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.996161	0.999487	0.999835	0.999932	0.999967	0.996161	1603	0.125	0.45 by 0.24 inch Hole
1A-4	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.996161	0.999487	0.999835	0.999932	0.999967	0.996161	1603	0.125	0.45 by 0.24 inch Hole
2A-1	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.996840	1605	0.125	None Visible
2A-3	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999798	0.996840	1605	0.125	None Visible
2A-2	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.996840	1605	0.125	None Visible
3A-1	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.999487	0.999835	0.999932	0.999967	0.985432	1603	0.125	0.45 by 0.24 inch Hole
3A-2	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.999487	0.999835	0.999932	0.999967	0.985432	1603	0.125	0.45 by 0.24 inch Hole
3A-3	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.999487	0.999835	0.999932	0.999967	0.985432	1603	0.125	0.45 by 0.24 inch Hole
4A-1	0.85	AFRSI	0.53	Rohacell	Skin / Stringer Al-Li	0.987095	0.998270	0.999443	0.999770	0.999889	0.998270	1605	0.125	None Visible
4A-2	0.85	AFRSI	0.53	Rohacell	Skin / Stringer Al-Li	0.987095	0.998270	0.999443	0.999770	0.999889	0.998270	1605	0.125	None Visible
1B-1	0.93	AFRSI	0.67	Rohacell	Skin / Stringer Al-Li	0.996161	0.999487	0.999835	0.999932	0.999967	0.999487	1605	0.125	None Visible
2B-1	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.996840	1605	0.125	None Visible
2B-1-OTF5	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.996840	1605	0.125	None Visible

Probability of No Impact

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	LOx Tank Top Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Modified 100 Mission MSFC Model For Area Difference Probability of No Impact (0.125 Inch)	Probability of No Impact (0.188 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
1A-1	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.985432	1603	0.125	0.45 by 0.24 inch Hole
1A-3	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.985432	1603	0.125	0.45 by 0.24 inch Hole
1A-2	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.985432	1603	0.125	0.45 by 0.24 inch Hole
1A-4	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.985432	1603	0.125	0.45 by 0.24 inch Hole
2A-1	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.976539	1603	0.125	0.45 by 0.24 inch Hole
2A-3	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.976539	1603	0.125	0.45 by 0.24 inch Hole
2A-2	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.976539	1603	0.125	0.45 by 0.24 inch Hole
3A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.985432	1603	0.125	0.45 by 0.24 inch Hole
3A-2	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.985432	1603	0.125	0.45 by 0.24 inch Hole
3A-3	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.985432	1603	0.125	0.45 by 0.24 inch Hole
4A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.987095	0.998270	0.999443	0.999770	0.999889	0.987095	1603	0.125	0.45 by 0.24 inch Hole
4A-2	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.987095	0.998270	0.999443	0.999770	0.999889	0.987095	1603	0.125	0.45 by 0.24 inch Hole
1B-1	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.985432	1603	0.125	0.45 by 0.24 inch Hole
2B-1	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.976539	1603	0.125	0.45 by 0.24 inch Hole
2B-1-OTF5	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.976539	1603	0.125	0.45 by 0.24 inch Hole

Probability of No Impact

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

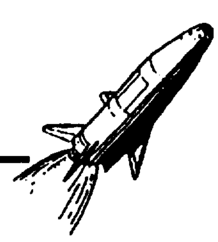
Vehicle Option	Probability of No Impact (0.125 inch)	Probability of No Impact (0.188 inch)	Probability of No Impact (0.250 inch)	Total Vehicle Probability of No Impact
1A-1	0.903214	0.986522	0.995644	0.936403
1A-3	0.903214	0.986522	0.995644	0.936403
1A-2	0.903214	0.986522	0.995644	0.974474
1A-4	0.903214	0.986522	0.995644	0.974474
2A-1	0.917142	0.988536	0.996299	0.936209
2A-3	0.917142	0.988536	0.996299	0.936209
2A-2	0.917142	0.988536	0.996299	0.969114
3A-1	0.880808	0.984644	0.995034	0.918847
3A-2	0.880808	0.984644	0.995034	0.962765
3A-3	0.880808	0.984644	0.995034	0.962765
4A-1	0.871825	0.981880	0.994135	0.925218
4A-2	0.871825	0.981880	0.994135	0.975782
1B-1	0.903214	0.986522	0.995644	0.981415
2B-1	0.917142	0.988536	0.996299	0.971826
2B-1-OTFS	0.904949	0.986774	0.995754	0.971295

Micrometeoroid Wrap-up Summary

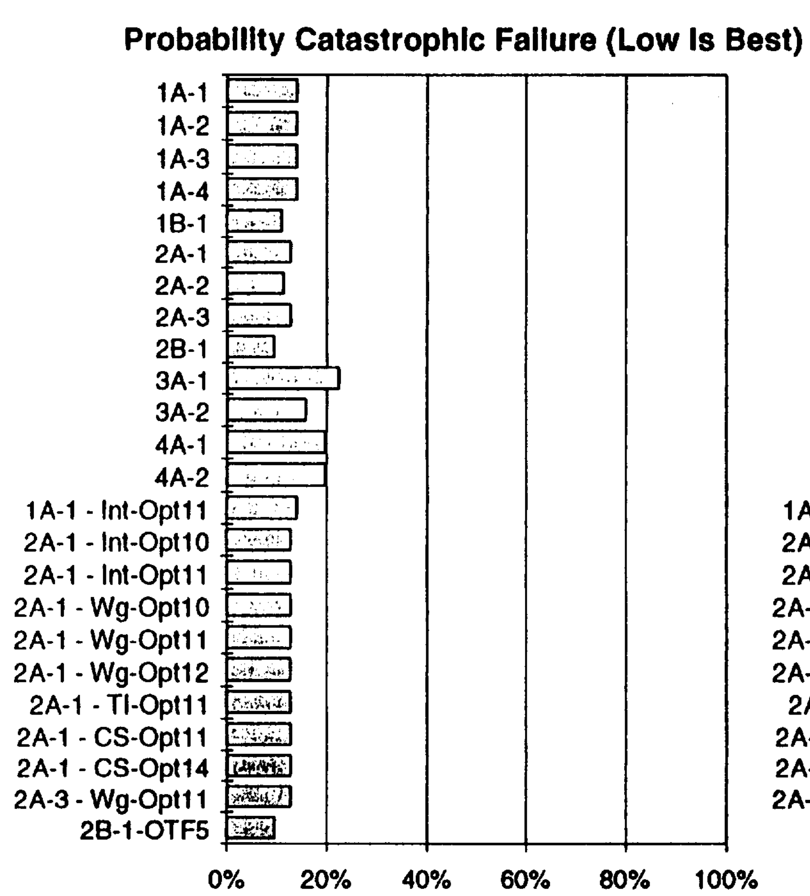
Vehicle Option	Total Vehicle Probability of Micrometeoroid Of No Impact MSFC Mission Profile	Total Vehicle Probability of Micrometeoroid Of No Impact MSFC Mission Profile	Total Vehicle Probability of Micrometeoroid Of No Catastrophe Failure MSFC Mission Profile	Total Vehicle Probability of Micrometeoroid Of No Catastrophe Failure MSFC Mission Profile
1A-1	0.926318	0.936403	0.988815	0.990243
1A-3	0.926318	0.936403	0.988815	0.990243
1A-2	0.963979	0.974474	0.988815	0.990243
1A-4	0.963979	0.974474	0.988815	0.990243
2A-1	0.915110	0.936209	0.987655	0.990661
2A-3	0.915110	0.936209	0.987655	0.990661
2A-2	0.968168	0.969114	0.990419	0.991387
3A-1	0.918847	0.918847	0.983224	0.984644
3A-2	0.962765	0.962765	0.987571	0.988997
3A-3	0.962765	0.962765	0.987571	0.988997
4A-1	0.928269	0.925218	0.986829	0.986829
4A-2	0.975782	0.975782	0.986829	0.986829
1B-1	0.980000	0.981415	0.992545	0.996064
2B-1	0.970877	0.971826	0.991060	0.995138
2B-1-OTF5	0.970035	0.971295	0.990201	0.994906

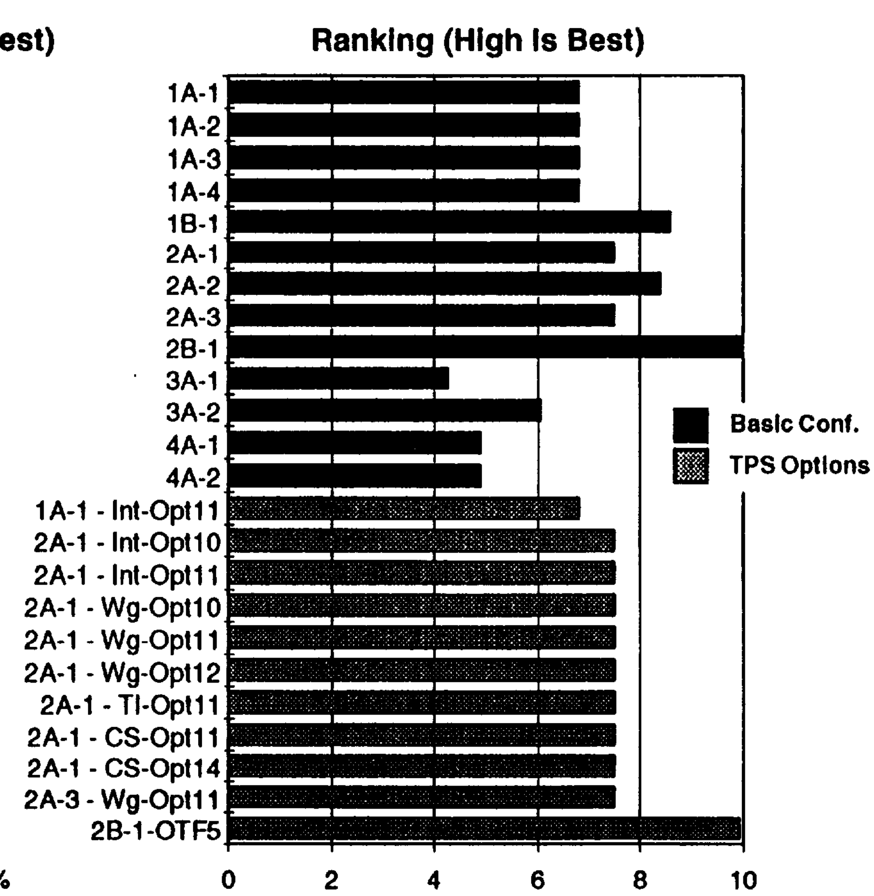
2B Options Ranked Best For Least Probability Of Catastrophic Failure

SSTO



8b. Susceptibility of tank rupture due to on-orbit debris impact - (Qualitative Analysis) - The candidate vehicle options are compared on the perceived susceptibility to tank rupture for vehicle on-orbit duration's of 900 days.





NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Non-Integral and Sandwich Construction are Best For Debris & Micrometeoroid Probability of No Rupture

SC - 8b Probability of No Catastrophe Failure (Allowing 0.70 Inch Diameter Hole)

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	LH2 Tank Bottom Debris Probability of No Rupture	LH2 Tank Top Debris Probability of No Rupture	LOx Tank Bottom Debris Probability of No Rupture	LOx Tank Top Debris Probability of No Rupture	LH2 Tank Bottom Micrometeoroid Probability of No Rupture	LH2 Tank Top Micrometeoroid Probability of No Rupture	LOx Tank Bottom Micrometeoroid Probability of No Rupture	LOx Tank Top Micrometeoroid Probability of No Rupture	Overall Probability of No Rupture
1A-1	0.937806	0.95421	0.988105	0.983607	0.998216	0.994465	0.998046	0.998046	0.859997
1A-2	0.937806	0.95421	0.988105	0.983607	0.998216	0.994465	0.998046	0.998046	0.859997
1A-3	0.937806	0.95421	0.988105	0.983607	0.998216	0.994465	0.998046	0.998046	0.859997
1A-4	0.937806	0.95421	0.988105	0.983607	0.998216	0.994465	0.998046	0.998046	0.859997
1B-1	0.937806	0.977019	0.994082	0.983607	0.998216	0.998216	0.998046	0.998046	0.889222
2A-1	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.996840	0.873004
2A-2	0.987569	0.965799	0.964028	0.973613	0.998676	0.995889	0.998983	0.996840	0.886644
2A-3	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.996840	0.873004
2B-1	0.987569	0.982887	0.964028	0.973613	0.998676	0.998676	0.998983	0.996840	0.904857
3A-1	0.859239	0.946553	0.988105	0.983607	0.993518	0.993518	0.998046	0.998046	0.777206
3A-2	0.927510	0.946553	0.988105	0.983607	0.997910	0.993518	0.998046	0.998046	0.842668
3A-3	0.927510	0.946553	0.988105	0.983607	0.997910	0.993518	0.998046	0.998046	0.842668
4A-1	0.917810	0.939316	0.960373	0.985467	0.997619	0.992616	0.998270	0.998270	0.805172
4A-2	0.917810	0.939316	0.960373	0.985467	0.997619	0.992616	0.998270	0.998270	0.805172
1A-1-Int-Opt 10	0.937806	0.954210	0.988105	0.983607	0.998216	0.994465	0.998046	0.998046	0.859997
2A-1-Int-Opt 10	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.996840	0.873004
2A-1-Int-Opt 11	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.996840	0.873004
2A-1-Wing-Opt 10	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.996840	0.873004
2A-1-Wing-Opt 11	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.996840	0.873004
2A-1-Wing-Opt 12	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.996840	0.873004
2A-1-Tail-Opt 11	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.996840	0.873004
2A-1-CS-Opt 11	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.996840	0.873004
2A-1-CS-Opt 14	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.996840	0.873004
2A-3-Wing-Opt 11	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.996840	0.873004
2B-1-OTF5	0.987569	0.982887	0.964028	0.973613	0.998243	0.998243	0.998983	0.996840	0.904072

SC - 8b Probability of No Catastrophe Failure (Allowing 0.70 Inch Diameter Hole)

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	LH2 Tank Bottom Debris Probability of No Rupture	LH2 Tank Top Debris Probability of No Rupture	LOx Tank Botttom Debris Probability of No Rupture	LOx Tank Top Debris Probability of No Rupture	LH2 Tank Bottom Micrometeoroid Probability of No Rupture	LH2 Tank Top Micrometeoroid Probability of No Rupture	LOx Tank Botttom Micrometeoroid Probability of No Rupture	LOx Tank Top Micrometeoroid Probability of No Rupture	Overall Probability of No Rupture
1A-1	0.937806	0.95421	0.988105	0.983607	0.998216	0.994465	0.998046	0.998046	0.859997
1A-2	0.937806	0.95421	0.988105	0.983607	0.998216	0.994465	0.998046	0.998046	0.859997
1A-3	0.937806	0.95421	0.988105	0.983607	0.998216	0.994465	0.998046	0.998046	0.859997
1A-4	0.937806	0.95421	0.988105	0.983607	0.998216	0.994465	0.998046	0.998046	0.859997
1B-1	0.937806	0.977019	0.994082	0.983607	0.998216	0.998216	0.998046	0.998046	0.889222
2A-1	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.99684	0.873004
2A-2	0.987569	0.965799	0.964028	0.973613	0.998676	0.995889	0.998983	0.99684	0.886644
2A-3	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.99684	0.873004
2B-1	0.987569	0.982887	0.964028	0.973613	0.998676	0.998676	0.998983	0.99684	0.904857
3A-1	0.859239	0.946553	0.988105	0.983607	0.993518	0.993518	0.998046	0.998046	0.777206
3A-2	0.92751	0.946553	0.988105	0.983607	0.99791	0.993518	0.998046	0.998046	0.842668
3A-3	0.92751	0.946553	0.988105	0.983607	0.99791	0.993518	0.998046	0.998046	0.842668
4A-1	0.91781	0.939316	0.960373	0.985467	0.997619	0.992616	0.99827	0.99827	0.805172
4A-2	0.91781	0.939316	0.960373	0.985467	0.997619	0.992616	0.99827	0.99827	0.805172
1A-1-Int-Opt 10	0.937806	0.95421	0.988105	0.983607	0.998216	0.994465	0.998046	0.998046	0.859997
2A-1-Int-Opt 10	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.99684	0.873004
2A-1-Int-Opt 11	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.99684	0.873004
2A-1-Wing-Opt 10	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.99684	0.873004
2A-1-Wing-Opt 11	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.99684	0.873004
2A-1-Wing-Opt 12	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.99684	0.873004
2A-1-Tail-Opt 11	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.99684	0.873004
2A-1-CS-Opt 11	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.99684	0.873004
2A-1-CS-Opt 14	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.99684	0.873004
2A-3-Wing-Opt 11	0.975097	0.965799	0.964028	0.973613	0.995889	0.995889	0.998983	0.99684	0.873004
2B-1-OTF5	0.987569	0.982887	0.964028	0.973613	0.998243	0.998243	0.998983	0.99684	0.904072

Probability of No Catastrophe Failure (Allowing 0.70 Inch Diameter Hole)
Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

			LH Tank			Modified 100 Mission MSFC Model For Area Difference								
			Bottom		Tank	Probability	Probability	Probability	Probability	Probability	Component	Test	Test	Test
Vehicle					Construction	of No Impact	of No Impact	of No Impact	of No Impact	of No Impact	Probability	Panel	Particle	Panel
Option	Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Type	(0.125 Inch)	(0.1875 Inch)	(0.250 Inch)	(0.3125 Inch)	(0.375 Inch)	of No Impact	Reference	Size	Results
1A-1	1.38	AFRSI	0.99	Rohacell	Skin / Stringer	0.702506	0.878576	0.937806	0.963045	0.975693	0.937806	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
1A-3	1.38	AFRSI	0.99	Rohacell	Skin / Stringer	0.702506	0.878576	0.937806	0.963045	0.975693	0.937806	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
1A-2	1.74	AFRSI	0.31+1.16	Rohacell	Honeycomb	0.702506	0.878576	0.937806	0.963045	0.975693	0.937806	1671	0.187	0.98 by 0.87 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
1A-4	1.74	AFRSI	.31+1.16	Rohacell	Honeycomb	0.702506	0.878576	0.937806	0.963045	0.975693	0.937806	1671	0.187	0.98 by 0.87 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
2A-1	0.50	AFRSI	0.38	Rohacell	Skin / Stringer	0.933628	0.976097	0.987569	0.992891	0.996218	0.976097	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
2A-3	0.50	AFRSI	0.38	Rohacell	Skin / Stringer	0.933628	0.976097	0.987569	0.992891	0.996218	0.976097	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
2A-2	0.50	AFRSI	1.50	Rohacell	Honeycomb	0.933628	0.976097	0.987569	0.992891	0.996218	0.987569	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
3A-1	0.76	AFRSI	0.58	Rohacell	Skin / Stringer	0.661130	0.859239	0.927510	0.956831	0.971574	0.859239	1605	0.125	None Visible
3A-2	1.05	AFRSI	.19+1.26	Rohacell	Honeycomb	0.661130	0.859239	0.927510	0.956831	0.971574	0.927510	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
3A-3	1.05	AFRSI	.19+1.26	Rohacell	Honeycomb	0.661130	0.859239	0.927510	0.956831	0.971574	0.927510	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
4A-1	1.12	AFRSI	0.81	Rohacell	Skin / Stringer	0.623992	0.841219	0.917810	0.950950	0.967667	0.917810	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
4A-2	1.25	AFRSI	0.19+1.16	Rohacell	Honeycomb	0.623992	0.841219	0.917810	0.950950	0.967667	0.917810	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
1B-1	0.55	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.702506	0.878576	0.937806	0.963045	0.975693	0.937806	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better
2B-1	0.50	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.933628	0.976097	0.987569	0.992891	0.996218	0.987569	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better
2B-1-OTF5	0.38	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.933628	0.976097	0.987569	0.990318	0.993786	0.987569	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better

Probability of No Catastrophe Failure (Allowing 0.70 Inch Diameter Hole)
Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

			LH Tank			Modified 100 Mission MSFC Model For Area Difference								
			Top		Tank	Probability	Probability	Probability	Probability	Probability	Component	Test	Test	Test
Vehicle					Construction	of No Impact	of No Impact	of No Impact	of No Impact	of No Impact	Probability	Panel	Particle	Panel
Option	Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Type	(0.125 Inch)	(0.188 Inch)	(0.250 Inch)	(0.3125 Inch)	(0.375 Inch)	of No Impact	Reference	Size	Results
1A-1	0.47	AFRSI	0.38	Rohacell	Skin / Stringer	0.879988	0.954210	0.977019	0.986459	0.991130	0.954210	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
1A-3	0.47	AFRSI	0.38	Rohacell	Skin / Stringer	0.879988	0.954210	0.977019	0.986459	0.991130	0.954210	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
1A-2	0.40	AFRSI	0.00+1.16	Rohacell	Honeycomb	0.879988	0.954210	0.977019	0.986459	0.991130	0.954210	1642	0.125	None Visible
1A-4	0.40	AFRSI	0.00+1.16	Rohacell	Honeycomb	0.879988	0.954210	0.977019	0.986459	0.991130	0.954210	1642	0.125	None Visible
2A-1	0.43	AFRSI	0.38	Rohacell	Skin / Stringer	0.909446	0.965799	0.982887	0.989929	0.993407	0.965799	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
2A-3	0.43	AFRSI	0.38	Rohacell	Skin / Stringer	0.909446	0.965799	0.982887	0.989929	0.993407	0.965799	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
2A-2	0.40	AFRSI	1.50	Rohacell	Honeycomb	0.909446	0.965799	0.982887	0.989929	0.993407	0.965799	1642	0.125	None Visible
3A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer	0.860858	0.946553	0.973122	0.984149	0.989613	0.946553	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
3A-2	0.40	AFRSI	0.00+1.26	Rohacell	Honeycomb	0.860858	0.946553	0.973122	0.984149	0.989613	0.946553	1642	0.125	None Visible
3A-3	0.40	AFRSI	0.00+1.26	Rohacell	Honeycomb	0.860858	0.946553	0.973122	0.984149	0.989613	0.946553	1642	0.125	None Visible
4A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer	0.843025	0.939316	0.969424	0.981955	0.988170	0.939316	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
4A-2	0.50	AFRSI	0.00+1.16	Rohacell	Honeycomb	0.843025	0.939316	0.969424	0.981955	0.988170	0.939316	1642	0.125	None Visible
1B-1	0.50	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.879988	0.954210	0.977019	0.986459	0.991130	0.977019	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better
2B-1	0.40	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.909446	0.965799	0.982887	0.989929	0.993407	0.982887	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better
2B-1-OTF5	0.38	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.909446	0.965799	0.982887	0.986459	0.991130	0.982887	1660	0.187	None Visible - Test Done for FRSI - AFRSI Assumed Better

Debris Impact Worksheet

R.L. Schmidt
3/9/95

Probability of No Catastrophe Failure (Allowing 0.70 Inch Diameter Hole)

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	LOx Tank Bottom Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Modified 100 Mission MSFC Model For Area Difference: Probability of No Impact (0.125 Inch)	Probability of No Impact (0.188 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
1A-1	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988106	0.994082	0.996525	0.997728	0.988105	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-3	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988106	0.994082	0.996525	0.997728	0.988105	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-2	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988106	0.994082	0.996525	0.997728	0.988105	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-4	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988106	0.994082	0.996525	0.997728	0.988105	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
2A-1	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.817541	0.928805	0.964028	0.978746	0.986059	0.964028	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
2A-3	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.817541	0.928805	0.964028	0.978746	0.986059	0.964028	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
2A-2	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.817541	0.928805	0.964028	0.978746	0.986059	0.964028	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
3A-1	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988106	0.994082	0.996525	0.997728	0.988105	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
3A-2	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988106	0.994082	0.996525	0.997728	0.988105	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
3A-3	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.967886	0.988106	0.994082	0.996525	0.997728	0.988105	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
4A-1	0.85	AFRSI	0.53	Rohacell	Skin / Stringer Al-Li	0.895578	0.960373	0.980144	0.988307	0.992343	0.960373	1605	0.125	None Visible
4A-2	0.85	AFRSI	0.53	Rohacell	Skin / Stringer Al-Li	0.895578	0.960373	0.980144	0.988307	0.992343	0.960373	1605	0.125	None Visible
1B-1	0.93	AFRSI	0.67	Rohacell	Skin / Stringer Al-Li	0.967886	0.988106	0.994082	0.996525	0.997728	0.994082	1605	0.125	None Visible
2B-1	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.967886	0.988106	0.994082	0.996525	0.997728	0.994082	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
2B-1-OTF5	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.948562	0.980826	0.990443	0.994384	0.996327	0.990443	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness

Probability of No Catastrophe Failure (Allowing 0.70 Inch Diameter Hole)

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	LOx Tank Top Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Modified 100 Mission MSFC Model For Area Difference: Probability of No Impact (0.125 Inch)	Probability of No Impact (0.188 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
1A-1	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.983607	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-3	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.983607	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-2	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.983607	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-4	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.983607	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
2A-1	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.929656	0.973613	0.986823	0.992252	0.994930	0.973613	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
2A-3	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.929656	0.973613	0.986823	0.992252	0.994930	0.973613	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
2A-2	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.929656	0.973613	0.986823	0.992252	0.994930	0.973613	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
3A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.983607	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
3A-2	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.983607	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
3A-3	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.983607	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
4A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.960855	0.985467	0.992765	0.995751	0.997221	0.985467	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
4A-2	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.960855	0.985467	0.992765	0.995751	0.997221	0.985467	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1B-1	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.955917	0.983607	0.991835	0.995204	0.996863	0.983607	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
2B-1	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.929656	0.973613	0.986823	0.992252	0.994930	0.973613	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
2B-1-OTF5	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.929656	0.973613	0.986823	0.992252	0.994930	0.973613	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)

Probability of No Catastrophe Failure (Allowing 0.70 Inch Diameter Hole)
Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	Probability of No Impact (0.125 Inch)	Probability of No Impact (0.188 Inch)	Probability of No Impact (0.250 Inch)	Total Vehicle Probability of No Impact
1A-1	0.571967	0.814794	0.903395	0.869724
1A-3	0.571967	0.814794	0.903395	0.869724
1A-2	0.571967	0.814794	0.903395	0.869724
1A-4	0.571967	0.814794	0.903395	0.869724
2A-1	0.645261	0.851619	0.923421	0.883915
2A-3	0.645261	0.851619	0.923421	0.883915
2A-2	0.645261	0.851619	0.923421	0.895221
3A-1	0.526578	0.790467	0.889913	0.790467
3A-2	0.526578	0.790467	0.889913	0.853273
3A-3	0.526578	0.790467	0.889913	0.853273
4A-1	0.452668	0.747830	0.865771	0.815918
4A-2	0.452668	0.747830	0.865771	0.815918
1B-1	0.571967	0.814794	0.903395	0.895901
2B-1	0.763923	0.905991	0.952210	0.939463
2B-1-OTF5	0.748672	0.899317	0.948724	0.936024

Debris Wrap-up Summary

Vehicle Option	Total Vehicle Probability Of No Impact MSFC Mission Profile	Total Vehicle Probability Of No Impact Modified MSFC Mission Profile	Total Vehicle Probability Of No Catastrophe Failure MSFC Mission Profile	Total Vehicle Probability Of No Catastrophe Failure Modified MSFC Mission Profile
1A-1	0.652526	0.715320	0.840916	0.869724
1A-3	0.652526	0.715320	0.840916	0.869724
1A-2	0.755264	0.827945	0.840916	0.869724
1A-4	0.755264	0.827945	0.840916	0.869724
2A-1	0.604185	0.733078	0.823421	0.883915
2A-3	0.604185	0.733078	0.823421	0.883915
2A-2	0.795113	0.823571	0.864287	0.895221
3A-1	0.624292	0.684368	0.764283	0.790467
3A-2	0.740978	0.812284	0.825010	0.853273
3A-3	0.740978	0.812284	0.825010	0.853273
4A-1	0.654406	0.654406	0.815918	0.815918
4A-2	0.795541	0.795541	0.815918	0.815918
1B-1	0.836778	0.865445	0.861017	0.895901
2B-1	0.809181	0.891654	0.847441	0.939463
2B-1-OTF5	0.809181	0.885086	0.847441	0.936024

Probability of No Catastrophe Failure (Allowing 0.70 Inch Diameter Hole)

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	Avg TPS Thickness (LH Tank Bottom)	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Probability of No Impact (0.125 Inch)	Probability of No Impact (0.1875 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
						Modified 100 Mission MSFC Model For Area Difference								
1A-1	1.38	AFRSI	0.99	Rohacell	Skin / Stringer	0.959218	0.994465	0.998216	0.999263	0.999643	0.998216	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
1A-3	1.38	AFRSI	0.99	Rohacell	Skin / Stringer	0.959218	0.994465	0.998216	0.999263	0.999643	0.998216	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
1A-2	1.74	AFRSI	0.31+1.16	Rohacell	Honeycomb	0.959218	0.994465	0.998216	0.999263	0.999643	0.998216	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
1A-4	1.74	AFRSI	.31+1.16	Rohacell	Honeycomb	0.959218	0.994465	0.998216	0.999263	0.999643	0.998216	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
2A-1	0.50	AFRSI	0.38	Rohacell	Skin / Stringer	0.991924	0.998920	0.999652	0.999856	0.999930	0.998920	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
2A-3	0.50	AFRSI	0.38	Rohacell	Skin / Stringer	0.991924	0.998920	0.999652	0.999856	0.999930	0.998920	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
2A-2	0.50	AFRSI	1.50	Rohacell	Honeycomb	0.991924	0.998920	0.999652	0.999856	0.999930	0.999652	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
3A-1	0.76	AFRSI	0.58	Rohacell	Skin / Stringer	0.952388	0.993518	0.997910	0.999136	0.999581	0.993518	1605	0.125	None Visible
3A-2	1.05	AFRSI	.19+1.26	Rohacell	Honeycomb	0.952388	0.993518	0.997910	0.999136	0.999581	0.997910	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
3A-3	1.05	AFRSI	.19+1.26	Rohacell	Honeycomb	0.952388	0.993518	0.997910	0.999136	0.999581	0.997910	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
4A-1	1.12	AFRSI	0.81	Rohacell	Skin / Stringer	0.945923	0.992616	0.997619	0.999016	0.999523	0.997619	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
4A-2	1.25	AFRSI	0.19+1.16	Rohacell	Honeycomb	0.945923	0.992616	0.997619	0.999016	0.999523	0.997619	1671	0.187	Assumed to Have no Damage (Based Upon 1642, 1643)
1B-1	0.55	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.959218	0.994465	0.998216	0.999263	0.999643	0.999263	1632	0 250	0.4 by 0.2 Inch Hole
2B-1	0.50	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.991924	0.998920	0.999852	0.999858	0.999930	0.999856	1632	0 250	0.4 by 0.2 Inch Hole
2B-1-OTF5	0.38	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.989299	0.998567	0.999539	0.999809	0.999908	0.999809	1632	0.250	0.4 by 0 2 Inch Hole

Probability of No Catastrophe Failure (Allowing 0.70 Inch Diameter Hole)

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	Avg TPS Thickness (LH Tank Top)	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Probability of No Impact (0.125 Inch)	Probability of No Impact (0.188 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
						Modified 100 Mission MSFC Model For Area Difference								
1A-1	0.47	AFRSI	0.38	Rohacell	Skin / Stringer	0.959218	0.994465	0.998216	0.999263	0.999643	0.994465	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-3	0.47	AFRSI	0.38	Rohacell	Skin / Stringer	0.959218	0.994465	0.998216	0.999263	0.999643	0.994465	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-2	0.40	AFRSI	0.00+1.16	Rohacell	Honeycomb	0.959218	0.994465	0.998216	0.999263	0.999643	0.994465	1641	0.125	Test Results For FRSI - AFRSI Assumed to be Better
1A-4	0.40	AFRSI	0.00+1.16	Rohacell	Honeycomb	0.959218	0.994465	0.998216	0.999263	0.999643	0.994465	1641	0.125	Test Results For FRSI - AFRSI Assumed to be Better
2A-1	0.43	AFRSI	0.38	Rohacell	Skin / Stringer	0.969570	0.995889	0.998678	0.999453	0.999735	0.995889	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
2A-3	0.43	AFRSI	0.38	Rohacell	Skin / Stringer	0.969570	0.995889	0.998678	0.999453	0.999735	0.995889	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
2A-2	0.40	AFRSI	1.50	Rohacell	Honeycomb	0.969570	0.995889	0.998676	0.999453	0.999735	0.995889	1642	0.125	None Visible
3A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer	0.952388	0.993518	0.997910	0.999136	0.999581	0.993518	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
3A-2	0.40	AFRSI	0.00+1.26	Rohacell	Honeycomb	0.952388	0.993518	0.997910	0.999136	0.999581	0.993518	1642	0.125	None Visible
3A-3	0.40	AFRSI	0.00+1.26	Rohacell	Honeycomb	0.952388	0.993518	0.997910	0.999136	0.999581	0.993518	1642	0.125	None Visible
4A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer	0.945923	0.992616	0.997619	0.999016	0.999523	0.992616	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
4A-2	0.50	AFRSI	0.00+1.16	Rohacell	Honeycomb	0.945923	0.992616	0.997619	0.999016	0.999523	0.992616	1642	0.125	None Visible
1B-1	0.50	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.959218	0.994465	0.998216	0.999263	0.999643	0.999263	1632	0.250	0.4 by 0.2 Inch Hole
2B-1	0.40	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.969570	0.995889	0.998676	0.999453	0.999735	0.999453	1632	0.250	0.4 by 0.2 Inch Hole
2B-1-OTF5	0.38	AFRSI	0.75	Rohacell	Non-Integral Honeycomb	0.959218	0.994465	0.998243	0.999266	0.999643	0.999266	1632	0.250	0.4 by 0.2 Inch Hole

Probability of No Catastrophe Failure (Allowing 0.70 Inch Diameter Hole)

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	LOx Tank Bottom: Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Modified 100 Mission MSFC Model For Area Difference: Probability of No Impact (0.125 Inch)	Probability of No Impact (0.188 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
1A-1	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.996161	0.999487	0.999835	0.999932	0.999967	0.999487	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-3	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.996161	0.999487	0.999835	0.999932	0.999967	0.999487	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-2	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.996161	0.999487	0.999835	0.999932	0.999967	0.999487	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-4	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.996161	0.999487	0.999835	0.999932	0.999967	0.999487	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
2A-1	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.998983	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
2A-3	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.998983	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
2A-2	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.998983	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
3A-1	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.999487	0.999835	0.999932	0.999967	0.999487	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
3A-2	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.999487	0.999835	0.999932	0.999967	0.999487	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
3A-3	0.50	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.999487	0.999835	0.999932	0.999967	0.999487	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
4A-1	0.85	AFRSI	0.53	Rohacell	Skin / Stringer Al-Li	0.987095	0.998270	0.999443	0.999770	0.999889	0.998270	1605	0.125	None Visible
4A-2	0.85	AFRSI	0.53	Rohacell	Skin / Stringer Al-Li	0.987095	0.998270	0.999443	0.999770	0.999889	0.998270	1605	0.125	None Visible
1B-1	0.93	AFRSI	0.67	Rohacell	Skin / Stringer Al-Li	0.996161	0.999487	0.999835	0.999932	0.999967	0.999487	1605	0.125	None Visible
2B-1	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.998983	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness
2B-1-OTF5	1.37	AFRSI	0.78	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999560	0.999796	0.998983	1607	0.187	1.0 by 0.50 Inch Hole - Assumed to be within .7 Inch Dia. Because of TPS Thickness

Probability of No Catastrophe Failure (Allowing 0.70 Inch Diameter Hole)

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

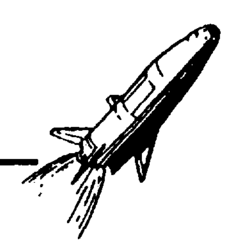
Vehicle Option	LOx Tank Top: Avg TPS Thickness	Type Of TPS	Avg Foam Thickness	Type Of Foam	Tank Construction Type	Modified 100 Mission MSFC Model For Area Difference: Probability of No Impact (0.125 Inch)	Probability of No Impact (0.188 Inch)	Probability of No Impact (0.250 Inch)	Probability of No Impact (0.3125 Inch)	Probability of No Impact (0.375 Inch)	Component Probability of No Impact	Test Panel Reference	Test Particle Size	Test Panel Results
1A-1	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.998046	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-3	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.998046	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1A-2	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.998046	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
1A-4	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.998046	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
2A-1	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.996840	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
2A-3	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.996840	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
2A-2	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.996840	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)
3A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.998046	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
3A-2	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.998046	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
3A-3	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.998046	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
4A-1	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.987095	0.998270	0.999443	0.999770	0.999889	0.998270	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
4A-2	0.40	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.987095	0.998270	0.999443	0.999770	0.999889	0.998270	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
1B-1	0.47	AFRSI	0.38	Rohacell	Skin / Stringer Al-Li	0.985432	0.998046	0.999371	0.999740	0.999874	0.998046	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
2B-1	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.996840	1603	0.125	0.45 by 0.24 inch Hole (Assumed Not A Problem)
2B-1-OTF5	0.52	AFRSI	0.39	Rohacell	Skin / Stringer Al-Li	0.976539	0.996840	0.998983	0.999580	0.999796	0.996840	1603	0.125	0.45 by 0.24 Inch Hole (Assumed Not A Problem)

Probability of No Catastrophe Failure (Allowing 0.70 Inch Diameter Hole)

Using Modified MSFC 100 Mission Debris Model Based Upon Tank Location (Changed Effective Area)

Vehicle Option	Probability of No Impact (0.125 Inch)	Probability of No Impact (0.188 Inch)	Probability of No Impact (0.250 Inch)	Total Vehicle Probability of No Impact
1A-1	0.903214	0.986522	0.995644	0.990243
1A-3	0.903214	0.986522	0.995644	0.990243
1A-2	0.903214	0.986522	0.995644	0.990243
1A-4	0.903214	0.986522	0.995644	0.990243
2A-1	0.917142	0.988536	0.996299	0.990661
2A-3	0.917142	0.988536	0.996299	0.990661
2A-2	0.917142	0.988536	0.996299	0.991367
3A-1	0.880808	0.984644	0.995034	0.984644
3A-2	0.880808	0.984644	0.995034	0.988997
3A-3	0.880808	0.984644	0.995034	0.988997
4A-1	0.871825	0.981880	0.994135	0.986629
4A-2	0.871825	0.981880	0.994135	0.986629
1B-1	0.903214	0.986522	0.995644	0.996064
2B-1	0.917142	0.988536	0.996299	0.995136
2B-1-OTF5	0.904949	0.986774	0.995754	0.994906

1A-1 Options And 1A-2 Ranked Best For Lowest Number Of Fracture Critical Joints



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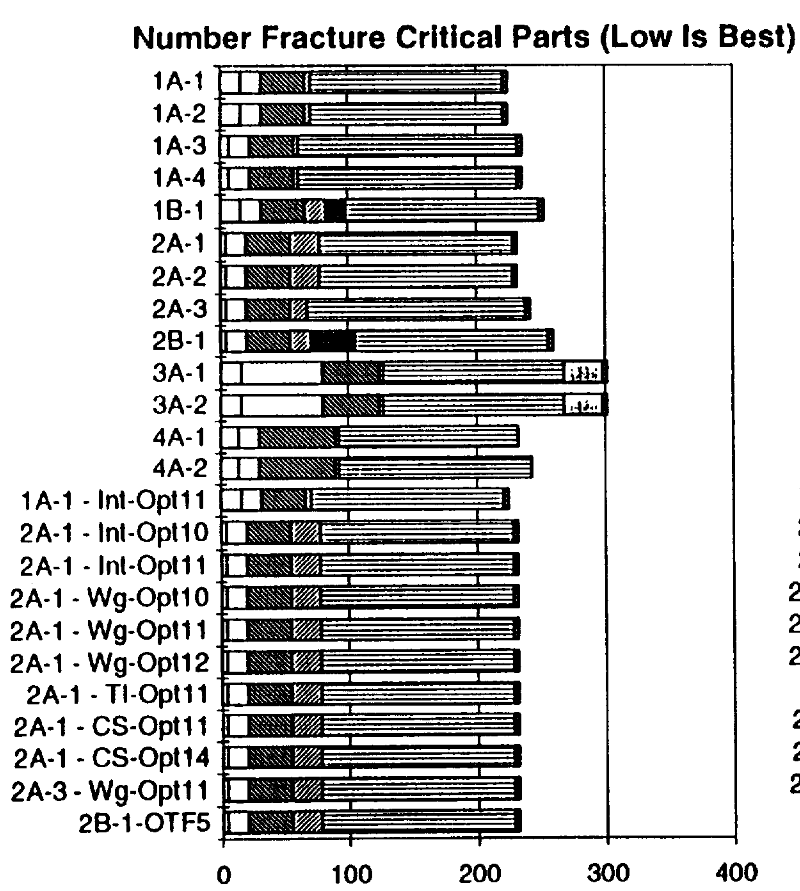
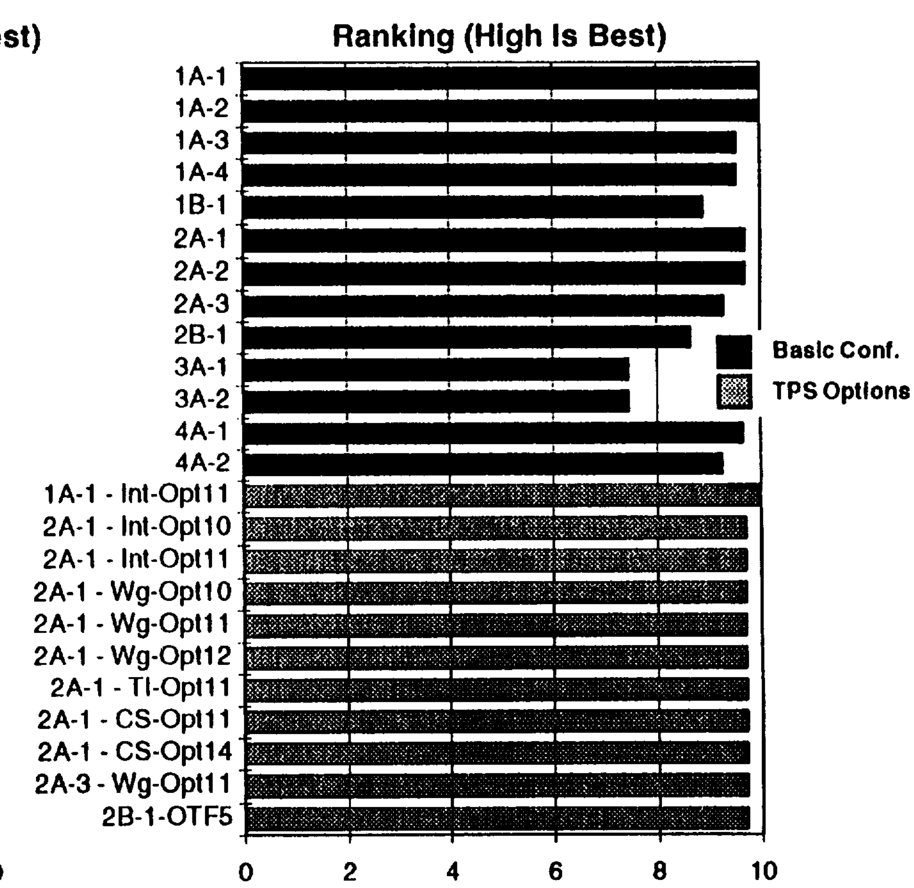
8c. Number of fracture critical joints - (Quantitative Analysis) - The candidate vehicle options are compared on the number of joints perceived to be fracture critical.





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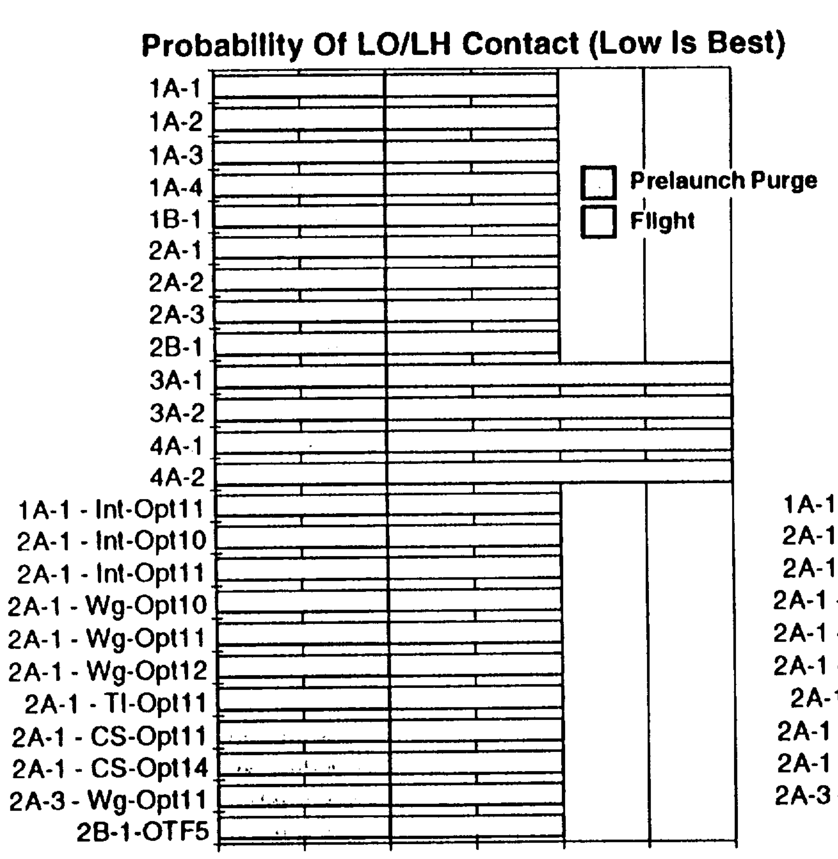
Jan 24 Certification matrix

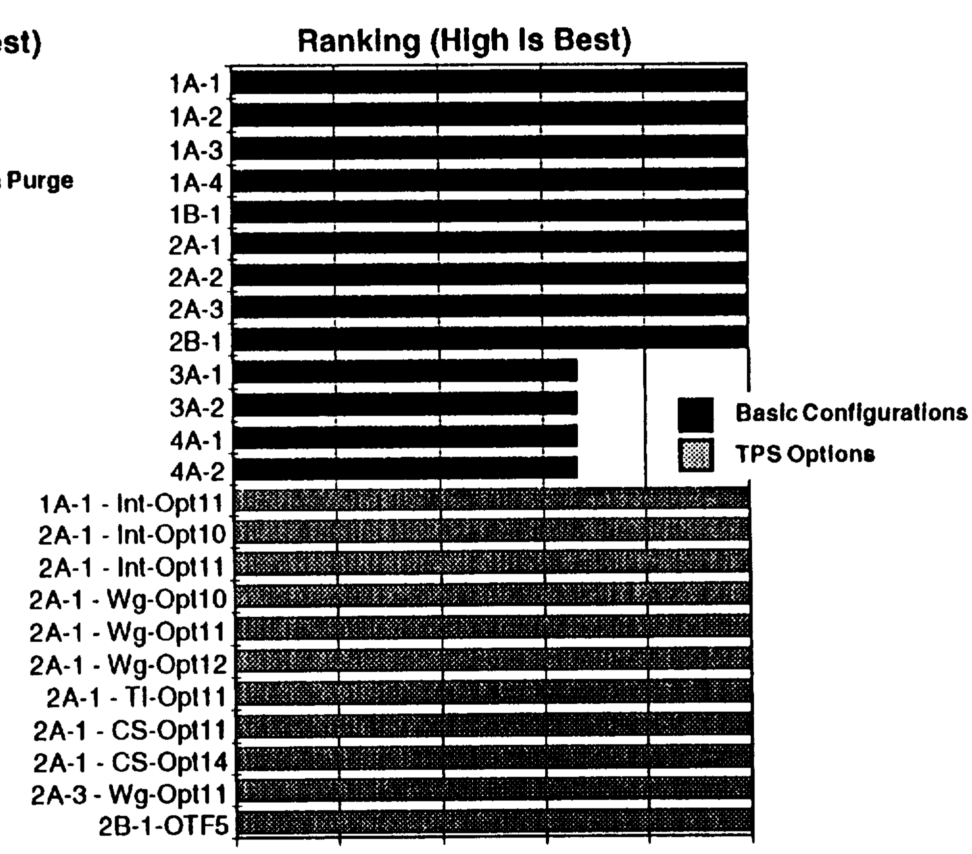
			SC-8c Number of Fracture critical parts							
Option	LO tank Parts	RP tank parts	Inter-tank parts	LH2 Tank parts	LH2 tk outer shell parts	Wing parts	Canard parts	Thrust structure	Aft skirt	Total
1A-1	16	16	35	4	0	150	0	0	4	225
1A -2	16	16	35	4	0	150	0	0	4	225
1A-3	7	16	35	4	0	170	0	0	4	236
1A-4	7	16	35	4	0	170	0	0	4	236
1B-1	16	16	35	16	16	150	0	0	4	253
2A-1	4	16	35	23	0	150	0	0	4	232
2A-2	4	16	35	23	0	150	0	0	4	232
2A-3	4	16	35	13	0	170	0	0	4	242
2B-1	4	16	35	16	35	150	0	0	4	260
3A-1	16	64	45	3	0	140	30	0	4	302
3A-2	16	64	45	3	0	140	30	0	4	302
4A-1	14	16	60	3	0	140	0	0	0	233
4A-2	14	16	60	3	0	150	0	0	0	243
1A-1-Int-Opt 10	16	16	35	4	0	150	0	0	4	225
2A-1-Int-Opt 10	4	16	35	23	0	150	0	0	4	232
2A-1-Int-Opt 11	4	16	35	23	0	150	0	0	4	232
2A-1-Wng-Opt 10	4	16	35	23	0	150	0	0	4	232
2A-1-Wng-Opt 11	4	16	35	23	0	150	0	0	4	232
2A-1-Wng-Opt 12	4	16	35	23	0	150	0	0	4	232
2A-1-Tail-Opt 11	4	16	35	23	0	150	0	0	4	232
2A-1-CS-Opt 11	4	16	35	23	0	150	0	0	4	232
2A-1-CS-Opt 14	4	16	35	23	0	150	0	0	4	232
2A-3-Wng-Opt 11	4	16	35	23	0	150	0	0	4	232
2B-1-OTF5	4	16	35	23	0	150	0	0	4	232

Options 3 And 4 Ranked Best For Lowest Potential For LH/LO Contact

SSTO

8d. Potential for/ LH/LO contact - (Qualitative evaluation) - The candidate vehicle options are compared on the potential of LH/LO contact that would be catastrophic.





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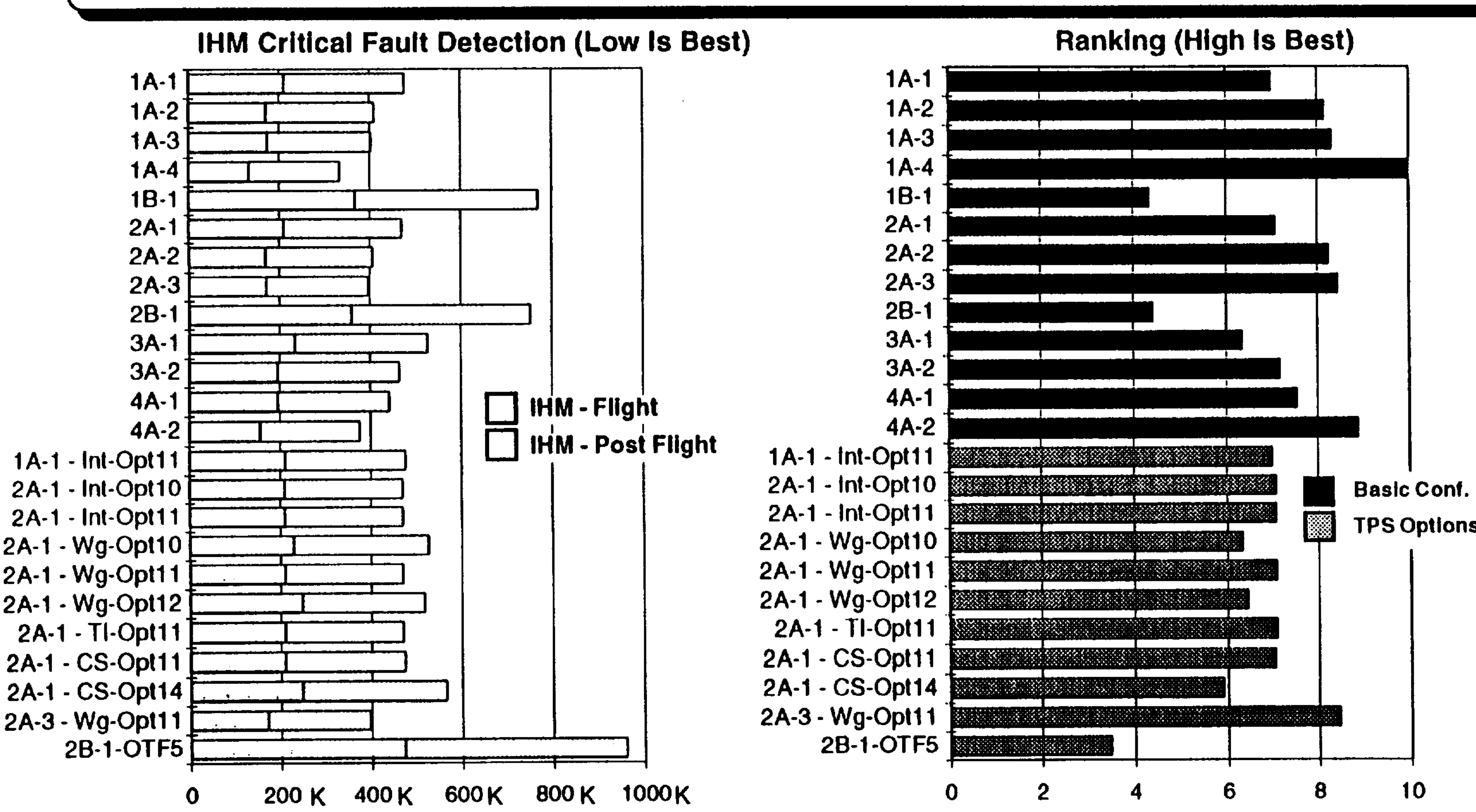
Jan 24 Certification matrix

			SC-8d Probability of LO/LH contact
Option	Score Prelaunch purge	Score flight	Total
1A-1	1	1	2
1A -2	1	1	2
1A-3	1	1	2
1A-4	1	1	2
1B-1	1	1	2
2A-1	1	1	2
2A-2	1	1	2
2A-3	1	1	2
2B-1	1	1	2
3A-1	1	2	3
3A-2	1	2	3
4A-1	1	2	3
4A-2	1	2	3
1A-1-Int-Opt 10	1	1	2
2A-1-Int-Opt 10	1	1	2
2A-1-Int-Opt 11	1	1	2
2A-1-Wng-Opt 10	1	1	2
2A-1-Wng-Opt 11	1	1	2
2A-1-Wng-Opt 12	1	1	2
2A-1-Tail-Opt 11	1	1	2
2A-1-CS-Opt 11	1	1	2
2A-1-CS-Opt 14	1	1	2
2A-3-Wng-Opt 11	1	1	2
2B-1-OTF5	1	1	2

1A-4 Option Ranked Best For Amenability of IHM To Detect Critical Faults

SSTO

8e. Amenability of IHM to detect critical faults - (Qualitative Analysis) - The candidate vehicle options are compared on the amenability of IHM to detect critical faults such as tank leakage, critical cracks in primary structure, TPS debond, insulation debond. etc.



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SAFETY - Amenability of IHM to Detect Critical Faults

The candidate vehicle options are compared on the amenability of IHM to detect critical faults such as critical cracks in the primary structure, TPS disbonds and insulation debond. For example, stringer skin constructions have a limited number of components (skin and TPS layers). However, the complexity of the design will cause more intensive instrumentation to monitor, more intensive inspections and more intensive maintenance in order to insure safe operation of the vehicle. This category is assessed on the surface are that these structures (tanks) will cover. The rationale being that the more surface area the structure has of a particularly difficult design the more difficult the structure will be to inspect, monitor and maintain. The critical features of these designs were considered to be stringer/skin designs, non-integrated designs and material selections.

In general, the safety - amenability of IHM to detect critical faults was based on several assumptions. These assumptions reflect the difficulties of inspection and instrumentation of the design configurations during in-flight monitoring and post-flight testing as applied to design and materials selections. This assessment of the different design configurations of SSTO is based on several general assumptions. These assumptions reflect the difficulties of inspection and instrumentation of the design configurations during the in-flight IHM and post flight inspections as applied to design and materials selection.

Design Assumptions

Several design considerations affect the ability of the structure to be inspected. Primary design considerations include the complexity of the design, the surface area to be inspected, the number of fracture critical components and the number of components to be inspected of instrumented.

Complexity of design

Inherently, simple designs tend to be better suited to inspection and instrumentation than do complex designs. The more complex designs, such as skin and stringer designs have a bend and protrusions that limit accessibility to hardware, inspection techniques, implementation and interpretation. It was also assumed that a more complex design may also require fabrication of specific tooling to facilitate inspection.

Surface Area

Since the NDI technologies to be employed by IHM/NDI are dependent on the area of coverage (rather than on the thickness of the hardware), larger surface areas would be more difficult to inspect and instrument. This implies that the elongated and multiple tank

designs are more difficult to inspect and instrument. This also implies that since the non integrated design configurations have an internal and external structure the area of surface coverage had effectively doubled.

Number of fracture critical components

The level of inspection will not be consistent over the entire vehicle. Fracture critical items (i.e., tank splices, stringers and fittings) will require more intensive inspections and instrumentation than less critical components. Therefore, design configurations that have the largest number of fracture critical components will require the largest number of inspections and instrumentations.

Number of components inspected

Non integrated design configurations have a larger surface area, are more complex and have more critical components. These problems directly affect the NDI/IHM programs by increasing the number of inspection points and area to be inspected.

Materials Assumptions

Due to a lack of information on the composite/TPS structures, it was assumed that the IM7/977-2, AFR 700, Gr/BMI, TMC composite materials and Al-Li alloys have approximately same adaptability to NDI/IHM techniques. In general, the TPS materials assumed that the flexible blanket insulation is considered non inspectable by means other than visual inspection and the C/SiC is more readily adaptable to NDI/IHM.

Critical feature factors

The critical feature factor is the assesment of the complexity of the structure as compared to the most basic design, the sandwich structure.

Critical feature factor of stringer designs

The critical feature factor of stringer design evaluation as applied to in-flight IHM monitoring indicated that This configuration has a greater number of critical points of instrumentation. The bond lines and corners associated with the stringer stiffeners are stress concentration points that would require a concentrated level of instrumentation. It is considered that the acoustic emission transducers would be concentrated along the stringers and that the configuration complexity would make the signals more difficult to interpret. A correction factor of 3.0 was applied to the stringer designs to compensate for these difficulties

The critical feature factor of stringer design evaluation as applied to post-flight inspections indicated that due to the tight bend radius would be difficult to evaluate using NDI techniques. Current laser based ultrasonics only allow for 30 degree angle from the inspection plane. This indicates that complex tooling would be required for inspection. This configuration has a greater number of critical points of interest. The bond lines and corners are stress concentration points that would require a concentrated level of inspection. A correction factor of 3.75 was applied to the stringer designs to compensate for these difficulties.

Critical feature factor of non integral designs

The critical feature factor of non integrated design evaluation as applied to in flight IHM monitoring indicated that these designs have multiple skins would effectively double the area for instrumentation. This design also increases the number of bond lines and a support structure for the internal tank that would increase the number of critical instumentation points. A correction factor of 2.0 was applied to non integral designs to compensate for these difficulties.

The critical feature factor of non integral design evaluation as applied to post flight inspections indicated that these designs have multiple skins would effectively double the area for instrumentation. This design also increases the number of bond lines and adds a support structure for the internal tank that would increase the number of critical inspection points. A correction factor of 2.0 was applied to non integral designs to compensate for these difficulties.

Critical feature factor of designs which utilize ceramic composites

The critical feature factor of designs that utilize ceramic composites (Blackglas) as applied to in flight IHM monitoring indicated that there has been limited application of NDI techniques applied to ceramic composites. However, since IHM will most likely involve strain measuring devices and acoustic emission, there is no reason to believe that this composite material will interfere with these techniques. A correction factor of 1.0 was applied to composite designs to compensate for these difficulties.

The critical feature factor of designs that utilize ceramic composites (Blackglas) as applied to post flight inspections indicated that there has been limited application of NDI techniques applied to ceramic composites. This indicated that inspection of this material may require advanced techniques or developement of techniques. A correction factor of 2.0 was applied to ceramic composite designs to compensate for these difficulties.

Critical feature factor of designs which utilize TABI or AFRSI blankets

The critical feature factor of designs that utilize TABI or AFRSI blankets as applied to in flight IHM monitoring indicated that there has been limited application of NDI techniques applied to TABI or AFRSI blankets. This indicated that inspection of this material may require advanced techniques or development of techniques. It is also expected that if these techniques cannot be developed and the blankets will not be monitored during flight. Therefore no correction is necessary (a correction factor of 1.0) for designs with TABI or AFRSI blankets.

The critical feature factor of designs that utilize TABI or AFRSI blankets as applied to post flight inspections indicated that there has been limited application of NDI techniques applied to TABI or AFRSI blankets. This indicated that inspection of this material may require advanced techniques or development of techniques. It is also expected that if these techniques cannot be developed the blankets will require a complete visual inspection. A correction factor of 1.5 was applied to designs with TABI or AFRSI blankets to compensate for these difficulties.

Critical feature factor of designs which utilize TPS mechanical attachments

The critical feature factor of designs that utilize TPS mechanical attachments as applied to in flight IHM monitoring indicated that there may be additional difficulties associated with that design. The addition of attachments and gaps indicated that inspection of this material may require concentrated inspections, advanced techniques or development of techniques. Therefore a correction of 2.0 for designs with TPS mechanical attachments was applied.

The critical feature factor of designs that utilize TPS mechanical attachments as applied to post flight inspections indicated that there may be additional difficulties associated with that design. The addition of attachments and gaps indicated that inspection of this material may require concentrated inspections, advanced techniques or development of techniques. Therefore a correction of 2.0 for designs with TPS mechanical attachments was applied.

Trade study process

The trade study consisted of a composite score for the in-flight IHM and post-flight inspection of each of the design configurations The composite score for each of these categories is based on composite structure configuration, fracture critical areas, general surface areas as applied to each component of each configuration. The score represents the relative difficulty level in inspecting each component. The two parts of the composite score (in-flight IHM and post-flight inspection) are weighted equally for the scope of this investigation. The scores are then converted to a 1 to 10 approximation based on 10 being the highest composite score.

The composite scores were based on several assumptions related to the design configurations. The following general and critical areas of inspections were derived from simplified tank structures. It was assumed that the critical areas of inspection only included the area up to the splice, not to the frame. The critical areas were doubled to account for a more intensive inspection or instrumentations. The wing attachment points were scored according to the wing attachment area. Due to the similarities between designs, the wing, nose, canard, payload canister areas are not included in this investigation.

The combined critical feature factor for each structure option was arrived through the following calculation:
No. of skins + No. of TPS layers = Subtotal
Subtotal X Critical Feature Factor = Combined Critical Feature Factor

Table 1. Estimated Surface Areas of Tanks

Configuration	LH2 Tank General	LH2 Tank Critical	LO2 Tank General	LO2 Tank Critical	RP Tank General
1A&B	6940	614	4565	422	1593
2A&B	6509	704	4805	277	1593
3	6591*	430	3250*	362	6190
4	7214*	417	3002*	405	1593

*excluding area of common bulkhead

Structure/TPS design analysis

The structures were rated according to its 1) No. of skins, 2) No. of TPS layers and 3) Critical feature factor for each of the two phases of the structures life. The critical feature factor corrects for complicated design features,(stringer and non integrated designs) and material deficiencies (ceramic composites and AFRI or TABI blankets) as applied to the NDE/IHM project. It was generally considered that these variables would increase the difficulty of inspection by an order of magnitude.

Table 2. Number of variables and applied difficulty factor

Trade Option	No. of skins	No. of TPS layers	Sub total	IHM in-flight Critical Feature Factor	Post-flight Critical Feature factor
1	1	2	3	3.0	3.75
2	2	2	4	1.0	2.0
5	4	3	7	4.0	4.0
7	4	3	7	4.0	4.0
8	1	2	3	3.0	3.75
9	2	2	4	1.0	2.0
10	2	2	4	2.0	2.0
11	2	2	4	1.0	2.0
12	1	1	2	6.0	5.0
13	1	1	2	3.0	3.75
14	1	1	2	6.0	10.0

Table 3. Critical feature factors

Design deficiency	IHM	Post-flight
Stringer design	3.0	3.75
non integral design	2.0	2.0
ceramic materials*	1.0	2.0
AFRI or TABI	1.0	1.5
TPS mechanical attachments**	2.0	2.0

*Blackglas Option 14

**Options 5, 10, 12 and 14

Table 4. Combined Critical Feature Factors

OPTION	Combined Critical Feature Factor for In-flight IHM	Combined Critical Feature Factor for Post-flight Inspection
1	9.0	11.25
2	4	8
5	28	28
7	28	28
8	9.0	11.25
9	4	8
10	8	8
11	4	8
12	12	10
13	6	7.5
14	12	20

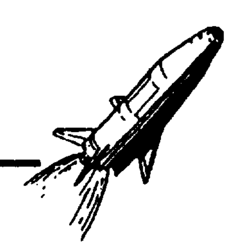
CONFIG		CRITICAL FEATURE FACTOR	LH2 GENERAL AREA	LH2 CRITICAL AREA	CRITICAL FEATURE FACTOR	LO2 GENERAL AREA	LO2 CRITICAL AREA	RP GENERAL AREA	CRITICAL FEATURE FACTOR	WING GENERAL AREA	WING ATTACH FACTOR	TOTALS	**RATING**
1A-1			6940	1228		4565	844	1593		4705	4705		
	IHM	9	62460	11052	9	41085	7596	14337	4	18820	56460	211810	
	POST	11.25	78075	13815	11.25	51356.25	9495	17921.25	8	37640	56460	264762.5	
												476572.5	**7.006583**
1A-2			6940	1228		4565	844	1593		4705	4705		
	IHM	4	27760	4912	9	41085	7596	14337	4	18820	56460	170970	
	POST	8	55520	9824	11.25	51356.25	9495	17921.25	8	37640	56460	238216.5	
												409186.5	**8.160448**
1A-3			6940	1228		4565	844	1593		4705	4705		
	IHM	9	62460	11052	9	41085	7596	14337	4	18820	18820	174170	
	POST	11.25	78075	13815	11.25	51356.25	9495	17921.25	8	37640	18820	227122.5	
												401292.5	**8.320975**
1A-4			6940	1228		4565	844	1593		4705	4705		
	IHM	4	27760	4912	9	41085	7596	14337	4	18820	18820	133330	
	POST	8	55520	9824	11.25	51356.25	9495	17921.25	8	37640	18828	200584.5	
												333914.5	**10**
1B-1			6940	1228		4565	844	1593		4705	4705		
	IHM	28	194320	34384	9	41085	7596	14337	4	18820	56460	367002	
	POST	28	194320	34384	11.25	51356.25	9495	17921.25	8	37640	56460	401576.5	
												768578.5	**4.344572**
2A-1			6509	1408		4805	554	1593		4705	4705		
	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												470477.3	**7.097357**

2A-2			6509	1408		4805	554	1593		4705	4705		
	IHM	4	26036	5632	9	43245	4986	14337	4	18820	56460	169516	
	POST	8	52072	11264	11.25	54056.25	6232.5	17921.25	8	37640	56460	235646	
												405162	**8.241506**
2A-3			6509	1408		4805	554	1593		4705	4705		
	IHM	9	58581	12672	9	43245	4986	14337	4	18820	18820	171461	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	18820	223736.3	
												395197.3	**8.449312**
2B-1			6509	1408		4805	554	1593		4705	4705		
	IHM	28	182252	39424	9	43245	4986	14337	4	18820	56460	359524	
	POST	28	182252	39424	11.25	54056.25	6232.5	17921.25	8	37640	56460	393986	
												753510	**4.431454**
3A-1			6591	860		3250	724	6190		4705	4705		
	IHM	9	59319	7740	9	29250	6516	55710	4	18820	56460	233815	
	POST	11.25	74148.75	9675	11.25	36562.5	8145	69637.5	8	37640	56460	292268.8	
												526083.8	**6.347174**
3A-2			6591	860		3250	724	6190		4705	4705		
	IHM	4	26364	3440	9	29250	6516	55710	4	18820	56460	196560	
	POST	8	52728	6880	11.25	36562.5	8145	69637.5	8	37640	56460	268053	
												464613	**7.186938**
3A-3			6591	860		3250	844	6190		4705	4705		
	IHM	4	26364	3440	9	29250	7596	55710	4	18820	18820	160000	
	POST	8	52728	6880	11.25	36562.5	9495	69637.5	8	37640	18820	231763	
												391763	**8.52338**
4A-1			7214	834		3002	810	1593		4705	4705		
	IHM	9	64926	7506	9	27018	7290	14337	4	18820	56460	196357	
	POST	11.25	81157.5	9382.5	11.25	33772.5	9112.5	17921.25	8	37640	56460	245446.3	
												441803.3	**7.557991**

4A-2			7214	834		3002	810	1593		4705	4705		
	IHM	4	28856	3336	9	27018	7290	14337	4	18820	56460	156117	
	POST	8	57712	6672	11.25	33772.5	9112.5	17921.25	8	37640	56460	219290.3	
												375407.3	**6.894727**
1A-1			6940	1228		4565	844	1593		4705	4705		
INT 11	IHM	9	62460	11052	9	41085	7596	14337	4	18820	56460	211810	
	POST	11.25	78075	13815	11.25	51356.25	9495	17921.25	8	37640	56460	264762.5	
												476572.5	**7.006583**
2A-1			6509	1408		4805	554	1593		4705	4705		
INT 10	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												470477.3	**7.097357**
2A-1			6509	1408		4805	554	1593		4705	4705		
INT 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												470477.3	**7.097357**
2A-1			6509	1408		4805	554	1593		4705	4705		
WG 10	IHM	9	58581	12672	9	43245	4986	14337	8	37640	56460	227921	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	16	75280	56460	299016.3	
												526937.3	**6.336893**
2A-1			6509	1408		4805	554	1593		4705	4705		
WG 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												470477.3	**7.097357**
2A-1			6509	1408		4805	554	1593		4705	4705		
WG 12	IHM	9	58581	12672	9	43245	4986	14337	12	56460	56460	246741	

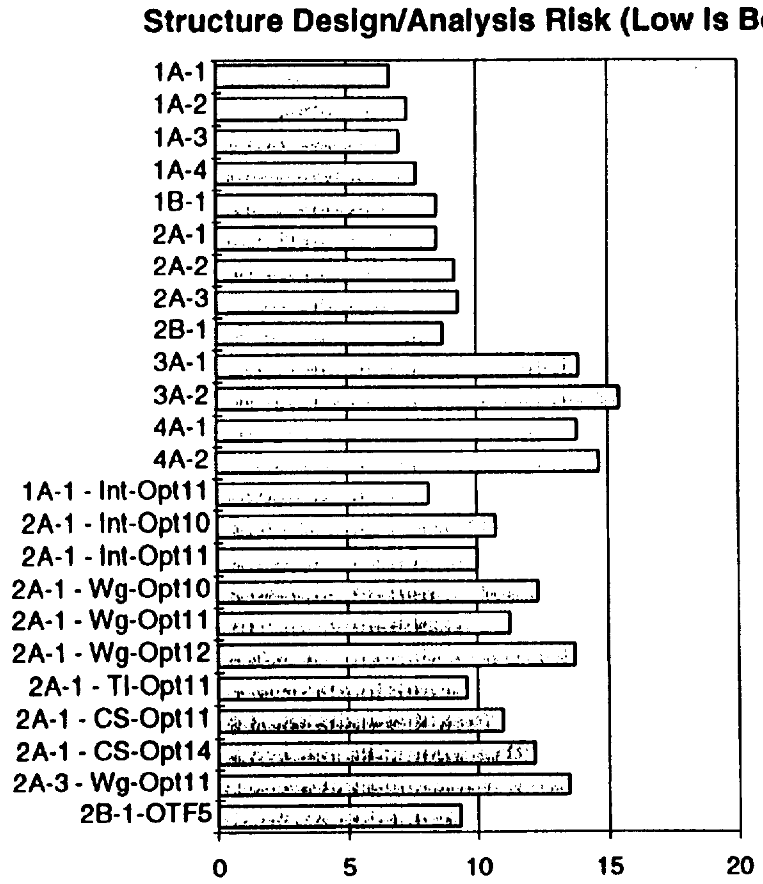
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	10	47050	56460	270786.3	
												517527.3	**6.452114**
2A-1			6509	1408		4805	554	1593		4705	4705		
TL 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												470477.3	**7.097357**
2A-1			6509	1408		4805	554	1593		4705	4705		
CS 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	56460	209101	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	56460	261376.3	
												470477.3	**7.097357**
2A-1			6509	1408		4805	554	1593		4705	4705		
CS 14	IHM	9	58581	12672	9	43245	4986	14337	12	56460	56460	246741	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	20	94100	56460	317836.3	
												564577.3	**5.914416**
2A-3			6509	1408		4805	554	1593		4705	4705		
WG 11	IHM	9	58581	12672	9	43245	4986	14337	4	18820	18820	171461	
	POST	11.25	73226.25	15840	11.25	54056.25	6232.5	17921.25	8	37640	18820	223736.3	
												395197.3	**8.449312**
2B-1			6509	1408		4805	554	1593		4705	4705		
OTF 5	IHM	28	182252	39424	9	43245	4986	14337	28	131740	56460	472444	
	POST	28	182252	39424	11.25	54056.25	6232.5	17921.25	28	131740	56460	488086	
												960530	**3.476357**

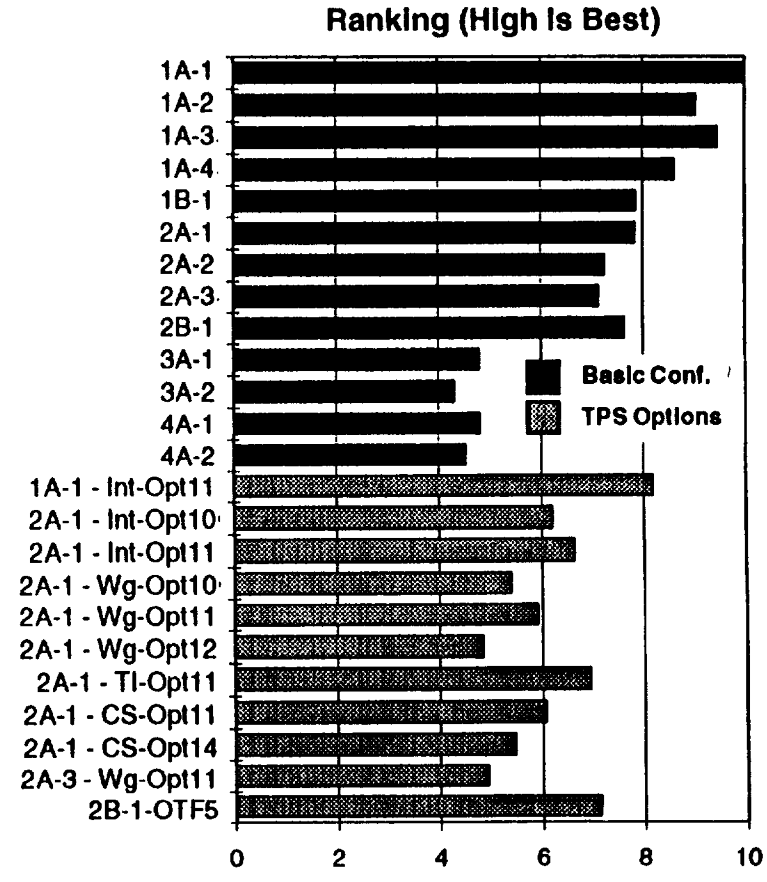
1A Options Ranked Best For Structural Design And Analysis Risk



SSTO

9a. Structural design and analysis risk- (Qualitative evaluation)- The candidate vehicle options are compared on the perceived risks associated with tank, and primary structure analysis and design foreseeable problems and potential problem resolution.





NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

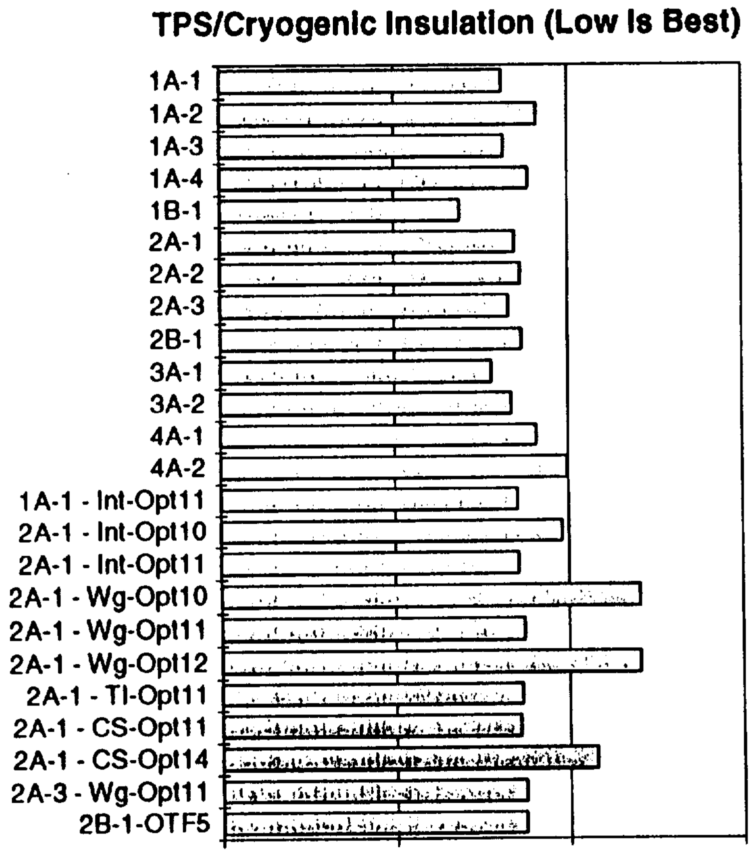
Jan 24 Certification matrix

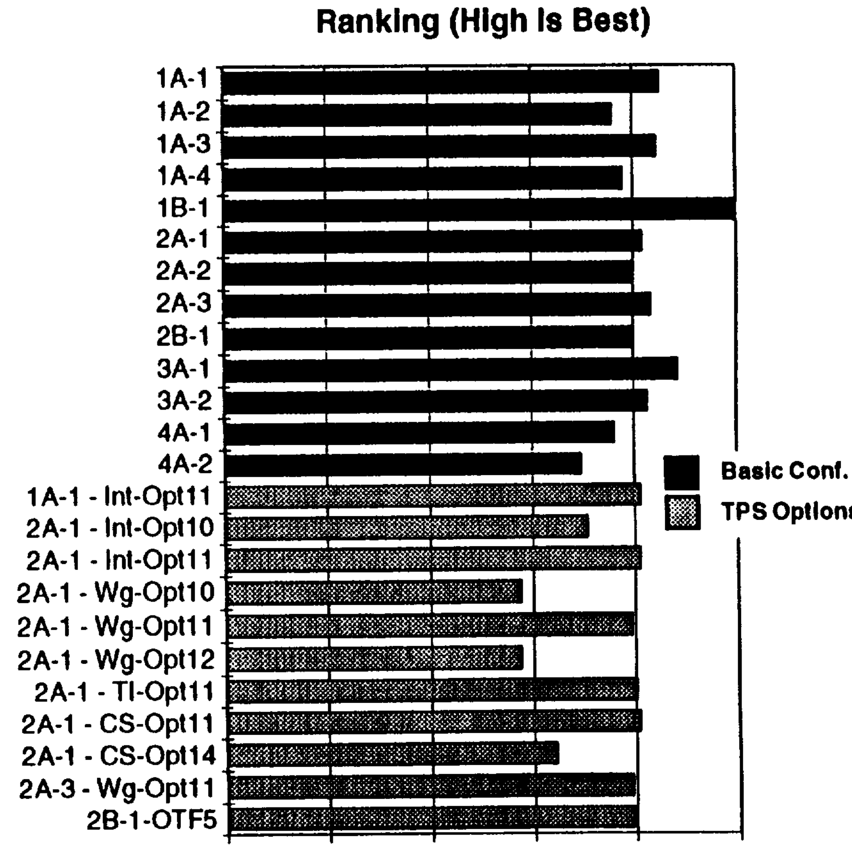
			SC-9a Structure Design/Analysis Risk																				
Option	LO tank	Wght	RP tank	Wght	Inter-tank	Wght	LH2 Tank	Wght	LH2 tank outer shell	Wght	Wing	Wght	Fairings	Wght	Canard	Wght	Thrust struct	Wght	Aft Skirt	Wght	Tail	Weight	Total score
1A-1	1	1.08	1	0.13	1	0.85	1	0.93	0	0	1	1.99	1	0.33	0	0	1	0.61	1.3	0.18	1	0.5	6.65
1A -2	1	1.08	1	0.13	1	0.85	1.4	1.16	0	0	1	1.99	1	0.33	0	0	1	0.61	1.3	0.18	1	0.5	7.35
1A-3	1.2	1.02	1	0.13	1	0.88	1	0.93	0	0	1	2.05	1	0.46	0	0	1	0.67	1.3	0.14	1	0.5	7.02
1A-4	1.2	1.02	1	0.13	1	0.88	1.4	1.16	0	0	1	2.05	1	0.46	0	0	1	0.67	1.3	0.14	1	0.5	7.71
1B-1	1	1.08	1	0.13	1	0.88	2.5	0.75	1	0.83	1	1.99	1	0.33	0	0	1	0.61	1.3	0.18	1	0.5	8.46
2A-1	1	0.96	1	0.13	1	1.12	2.5	1.01	0	0	1	2.01	1	0.4	0	0	1	0.61	1.3	0.17	1	0.5	8.47
2A-2	1	0.96	1	0.13	1	1.12	2.9	1.13	0	0	1	2.01	1	0.4	0	0	1	0.61	1	0.17	1	0.5	9.17
2A-3	1	0.96	1	0.13	1	1.15	1	0.89	0	0	2	2.18	1	0.53	0	0	1	0.67	1	0.14	1	0.5	9.32
2B-1	1	0.96	1	0.13	1	1.15	2.5	0.74	1	0.84	1	1.96	1	0.42	0	0	1	0.60	1	0.31	1	0.5	8.71
3A-1	4	1.37	1	0.16	1.2	0.60	4	0.94	0	0	1	1.93	1	0.34	1	0.19	1	0.64	1	0.18	1	0.5	13.90
3A-2	4	1.37	1	0.16	1.2	0.60	4.4	1.2	0	0	1	1.93	1	0.34	1	0.19	1	0.64	1	0.22	1	0.5	15.46
4A-1	4	1.21	1	0.13	1.5	1.35	3	1.13	0	0	1	1.83	1	0	0	0	1.4	0.80	0	0.00	1	0.5	13.83
4A-2	4	1.21	1	0.13	1.5	1.35	3	1.46	0	0	1	1.83	1	0.17	0	0	1.2	0.67	0	0.00	1	0.5	14.68
1A-1-Int-Opt 11	1	1.08	1	0.13	2.5	0.95	1	0.94	0	0	1	1.99	1	0.33	0	0	1	0.61	1	0.18	1	0.5	8.13
2A-1-Int-Opt 10	1	0.96	1	0.13	2.5	1.12	2.9	1.01	0	0	1	2.01	1	0.4	0	0	1	0.69	1	0.31	1	0.5	10.71
2A-1-Int-Opt 11	1	0.96	1	0.13	2	1.12	2.9	1.01	0	0	1	2.01	1	0.4	0	0	1	0.69	1	0.17	1	0.5	10.02
2A-1-Wng-Opt 10	1	0.96	1	0.13	1	1.12	2.9	1.01	0	0	2.5	2.18	1	0.4	0	0	1	0.69	1	0.17	1	0.5	12.34
2A-1-Wng-Opt 11	1	0.96	1	0.13	1	1.12	2.9	1.01	0	0	2	2.18	1	0.4	0	0	1	0.69	1	0.17	1	0.5	11.25
2A-1-Wng-Opt 12	1	0.96	1	0.13	1	1.12	2.9	1.01	0	0	2.5	2.74	1	0.4	0	0	1	0.69	1	0.17	1	0.5	13.74
2A-1-Tail-Opt 11	1	0.96	1	0.13	1	1.12	2.9	1.01	0	0	1	2.01	1	0.4	0	0	1	0.69	1	0.17	2	0.59	9.58
2A-1-CS-Opt 11	1	0.96	1	0.13	1	1.12	2.9	1.01	0	0	2	2.04	1	0.4	0	0	1	0.69	1	0.17	1	0.5	10.97
2A-1-CS-Opt 14	1	0.96	1	0.13	1	1.12	2.9	1.01	0	0	2.5	2.11	1	0.4	0	0	1	0.69	1	0.17	1	0.5	12.17
2A-3-Wng-Opt 11	1	0.96	1	0.13	1	1.12	2.9	1.01	0	0	3	2.20	1	0.4	0	0	1	0.69	1	0.17	1	0.5	13.49
2B-1-OTF5	1	0.96	1	0.13	1	1.16	2.5	0.74	1	0.84	1.3	1.96	1	0.42	0	0	1	0.60	1	0.31	1	0.5	9.31

1B-1 Option Ranked Best For Thermal Design Risk

SSTO

9b. Thermal Design Risk-(Qualitative evaluation)- The candidate vehicle options are compared on the perceived risks associated with insulation, and TPS thermal analysis and design foreseeable problems and potential problem resolution.



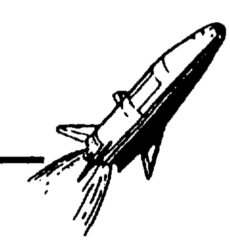


NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Jan 24 Certification matrix

			SC-9b TPS/Cryogenic Insulation Design/Analysis Risk																				
Option	LO tank	Wght	RP tank	Wght	Inter-tank	Wght	LH2 Tank	Wght	LH2 tank outer shell	Wght	Wing	Wght	Fairings	Wght	Canard	Wght	Thrust struct	Wght	Aft Skirt	Wght	Tail	Weigh	Total
1A-1	1.3	1.08	0	0.13	1	0.85	3	0.93	0	0	1	1.99	0.3	0.33	0	0	1	0.61	1	0.18	1	0.5	8.42
1A -2	1.3	1.08	0	0.13	1	0.85	3	1.16	0	0	1	1.99	0.3	0.33	0	0	1	0.61	1	0.18	1	0.5	9.11
1A-3	1	1.02	0	0.13	1	0.88	3	0.93	0	0	1	2.05	0.3	0.46	0	0	1	0.67	1	0.14	1	0.5	8.18
1A-4	1	1.02	0	0.13	1	0.88	3	1.16	0	0	1	2.05	0.3	0.46	0	0	1	0.67	1	0.14	1	0.5	8.87
1B-1	1	1.08	0	0.13	1	0.88	1	0.75	1	0.83	1	1.99	0.3	0.33	0	0	1	0.61	1	0.18	1	0.5	6.92
2A-1	2.5	0.96	0	0.13	1	1.12	1.5	1.01	0	0	1	2.01	0.4	0.4	0	0	1	0.61	1	0.17	1	0.5	8.47
2A-2	2.5	0.96	0	0.13	1	1.12	1.5	1.13	0	0	1	2.01	0.4	0.4	0	0	1	0.61	1	0.17	1	0.5	8.65
2A-3	2.5	0.96	0	0.13	1	1.15	1.2	0.89	0	0	1	2.18	0.4	0.53	0	0	1	0.67	1	0.14	1	0.5	8.30
2B-1	2.5	0.96	0	0.13	1	1.15	1	0.74	1	0.84	1	1.96	0.4	0.42	0	0	1	0.60	1	0.31	1	0.5	8.66
3A-1	1.3	1.37	0	0.16	1	0.60	2	0.94	0	0	1	1.93	0.3	0.34	1	0.19	1	0.64	1	0.18	1	0.5	7.81
3A-2	1.3	1.37	0	0.16	1	0.60	2	1.2	0	0	1	1.93	0.3	0.34	1	0.19	1	0.64	1	0.22	1	0.5	8.37
4A-1	1	1.21	0	0.13	1	1.35	3	1.13	0	0	1	1.83	0	0	0	0	1	0.80	0	0.00	1	0.5	9.08
4A-2	1	1.21	0	0.13	1	1.35	3	1.46	0	0	1	1.83	0.1	0.17	0	0	1	0.67	0	0.00	1	0.5	9.96
1A-1-Int-Opt 11	1.3	1.08	0	0.13	1	0.95	3	0.94	0	0	1	1.99	0.3	0.33	0	0	1	0.61	1	0.18	1	0.5	8.54
2A-1-Int-Opt 10	2.5	0.96	0	0.13	2	1.12	1.5	1.01	0	0	1	2.01	0.4	0.4	0	0	1	0.69	1	0.31	1	0.5	9.80
2A-1-Int-Opt 11	2.5	0.96	0	0.13	1	1.12	1.5	1.01	0	0	1	2.01	0.4	0.4	0	0	1	0.69	1	0.17	1	0.5	8.55
2A-1-Wng-Opt 10	2.5	0.96	0	0.13	2	1.12	1.5	1.01	0	0	2	2.18	0.4	0.4	0	0	1	0.69	1	0.17	1	0.5	12.02
2A-1-Wng-Opt 11	2.5	0.96	0	0.13	1	1.12	1.5	1.01	0	0	1	2.18	0.4	0.4	0	0	1	0.69	1	0.17	1	0.5	8.72
2A-1-Wng-Opt 12	2.5	0.96	0	0.13	1	1.12	1.5	1.01	0	0	2	2.74	0.4	0.4	0	0	1	0.69	1	0.17	1	0.5	12.02
2A-1-Tail-Opt 11	2.5	0.96	0	0.13	1	1.12	1.5	1.01	0	0	1	2.01	0.4	0.4	0	0	1	0.69	1	0.17	1	0.59	8.64
2A-1-CS-Opt 11	2.5	0.96	0	0.13	1	1.12	1.5	1.01	0	0	1	2.04	0.4	0.4	0	0	1	0.69	1	0.17	1	0.5	8.58
2A-1-CS-Opt 14	2.5	0.96	0	0.13	1	1.12	1.5	1.01	0	0	2	2.11	0.4	0.4	0	0	1	0.69	1	0.17	1	0.5	10.76
2A-3-Wng-Opt 11	2.5	0.96	0	0.13	1	1.12	1.5	1.01	0	0	1	2.20	0.4	0.4	0	0	1	0.69	1	0.17	1	0.5	8.74
2B-1-OTF5	2.5	0.96	0	0.13	0	1.16	1.5	0.74	2	0.84	1	1.96	0.4	0.42	0	0	1	0.60	1	0.31	1	0.5	8.71

Option 1A Ranked Best For Technology Development Needs



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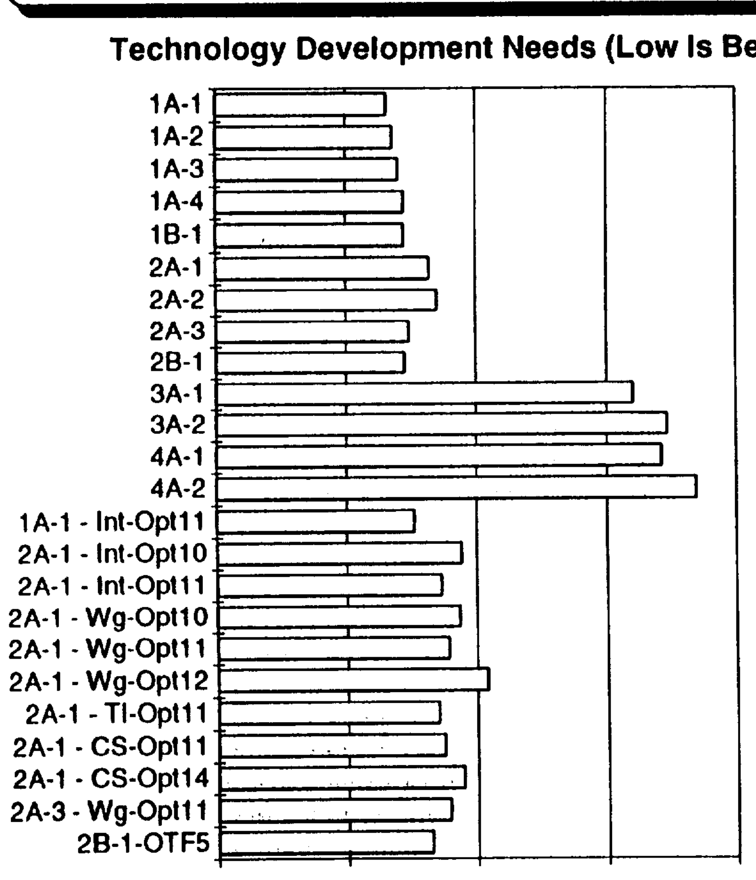
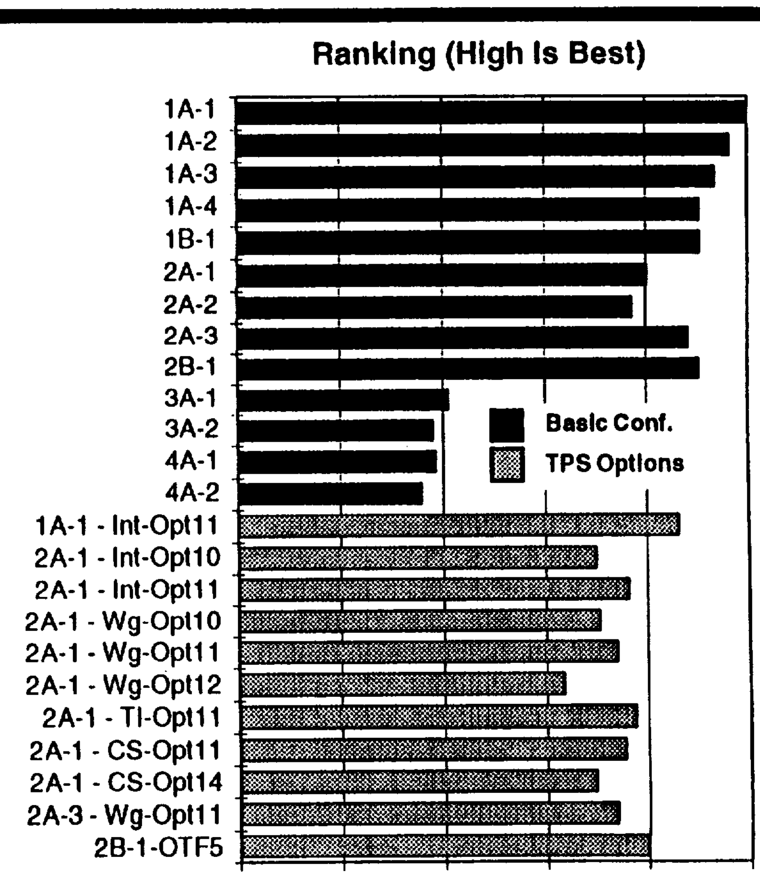
9c. Technology Development Needs- (Qualitative evaluation)- The candidate vehicle options are compared on the current technology development needs and perceived assessment of the magnitude of the development required.





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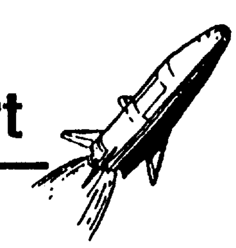
Jan 24 Certification matrix

			SC-9c Technology Development Needs																				
Option	LO tank	Wght	RP tank	Wght	Inter-tank	Wght	LH2 Tank	Wght	LH2 tank outer shell	Wght	Wing	Wght	Fairings	Wght	Canard	Wght	Thrust struct	Wght	Aft Skirt	Wght	Tail	Weigh	Total
1A-1	1.2	1.08	0	0.13	1	0.85	1	0.93	0	0	1	1.99	1.3	0.33	0	0	1	0.61	0	0.18	1	0.5	6.59
1A -2	1.2	1.08	0	0.13	1	0.85	1	1.16	0	0	1	1.99	1.3	0.33	0	0	1	0.61	0	0.18	1	0.5	6.82
1A-3	1	1.02	0	0.13	1	0.88	1	0.93	0	0	1.2	2.05	1.3	0.46	0	0	1	0.67	0	0.14	1	0.5	7.04
1A-4	1	1.02	0	0.13	1	0.88	1	1.16	0	0	1.2	2.05	1.3	0.46	0	0	1	0.67	0	0.14	1	0.5	7.27
1B-1	1.2	1.08	0	0.13	1	0.88	1	0.75	1	0.83	1	1.99	1.3	0.33	0	0	1	0.61	0	0.18	1	0.5	7.27
2A-1	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	1	2.01	1.3	0.4	0	0	1	0.61	0	0.17	1	0.5	8.22
2A-2	1	0.96	0	0.13	1	1.12	2.5	1.13	0	0	1	2.01	1.3	0.4	0	0	1	0.61	0	0.17	1	0.5	8.52
2A-3	1	0.96	0	0.13	1	1.15	1	0.89	0	0	1.2	2.18	1.3	0.53	0	0	1	0.67	0	0.14	1	0.5	7.45
2B-1	1	0.96	0	0.13	1.1	1.15	1	0.74	1	0.84	1	1.96	1	0.42	0	0	1	0.60	0	0.31	1	0.5	7.29
3A-1	5	1.37	0	0.16	1.2	0.60	5	0.94	0	0	1	1.93	1.5	0.34	1	0.19	1	0.64	0	0.18	1	0.5	16.04
3A-2	5	1.37	0	0.16	1.2	0.60	5	1.2	0	0	1	1.93	1.5	0.34	1	0.19	1	0.64	0	0.22	1	0.5	17.34
4A-1	5	1.21	0	0.13	1.1	1.35	5	1.13	0	0	1	1.83	1	0	0	0	2	0.80	0	0.00	1	0.5	17.12
4A-2	5	1.21	0	0.13	1.2	1.35	5	1.46	0	0	1.1	1.83	1	0.17	0	0	1.2	0.67	0	0.00	1	0.5	18.46
1A-1-Int-Opt 11	1.2	1.08	0	0.13	2	0.95	1	0.94	0	0	1	1.99	1.3	0.33	0	0	1	0.61	0	0.18	1	0.5	7.64
2A-1-Int-Opt 10	1	0.96	0	0.13	2	1.12	2.5	1.01	0	0	1	2.01	1.3	0.4	0	0	1	0.69	0	0.31	1	0.5	9.42
2A-1-Int-Opt 11	1	0.96	0	0.13	1.3	1.12	2.5	1.01	0	0	1	2.01	1.3	0.4	0	0	1	0.69	0	0.17	1	0.5	8.64
2A-1-Wng-Opt 10	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	1.4	2.18	1.3	0.4	0	0	1	0.69	0	0.17	1	0.5	9.34
2A-1-Wng-Opt 11	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	1.2	2.18	1.3	0.4	0	0	1	0.69	0	0.17	1	0.5	8.91
2A-1-Wng-Opt 12	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	1.5	2.74	1.3	0.4	0	0	1	0.69	0	0.17	1	0.5	10.40
2A-1-Tail-Opt 11	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	1	2.01	1.3	0.4	0	0	1	0.69	0	0.17	1.2	0.59	8.51
2A-1-CS-Opt 11	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	1.2	2.04	1.3	0.4	0	0	1	0.69	0	0.17	1	0.5	8.74
2A-1-CS-Opt 14	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	1.5	2.11	1.3	0.4	0	0	1	0.69	0	0.17	1	0.5	9.46
2A-3-Wng-Opt 11	1	0.96	0	0.13	1	1.12	2.5	1.01	0	0	1.2	2.20	1.3	0.4	0	0	1	0.69	0	0.17	1	0.5	8.93
2B-1-OTF5	1	0.96	0	0.13	1	1.16	2	0.74	1.4	0.84	1	1.96	1	0.42	0	0	1	0.60	0	0.31	1	0.5	8.26

Major Categories Summarized To Top Level Chart



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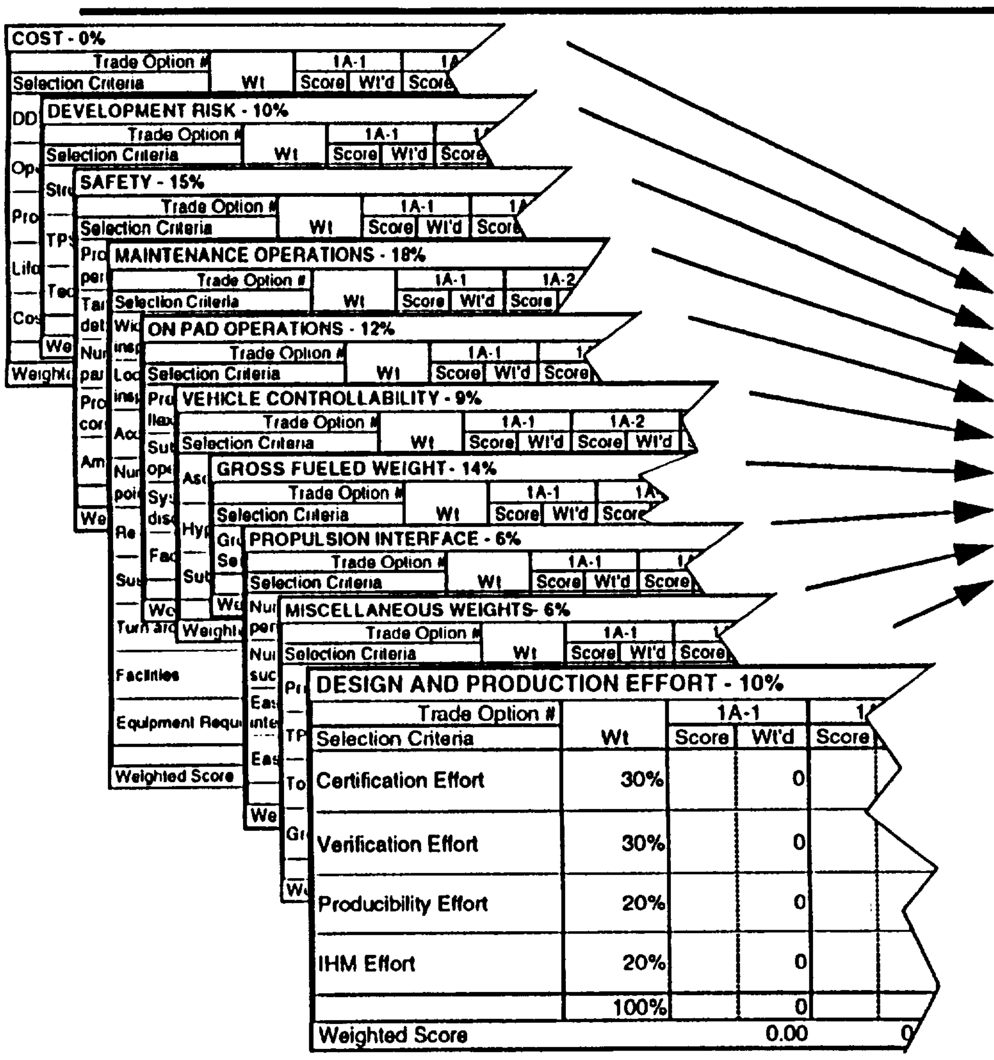

DESIGN AND PRODUCTION EFFORT - 10%				
Trade Option #		1A-1		1
Selection Criteria	Wt	Score	Wt'd	Score
Certification Effort	30%		0	
Verification Effort	30%		0	
Producibility Effort	20%		0	
IHM Effort	20%		0	
	100%		0	
Weighted Score			0.00	0

TOP LEVEL RESULTS					
Trade Option #		1A-1		1A-2	
Selection Criteria	Wt	Score	Wt'd	Score	W
DESIGN AND PRODUCTION EFFORT	10%	0	0	0	
MISCELLANEOUS WEIGHTS	6%	0	0	0	
GROSS FUELED WEIGHT SENSITIVITY	14%	0	0	0	
PROPULSION INTERFACE	6%	0	0	0	
VEHICLE CONTROLLABILITY	9%	0	0	0	
ON PAD OPERATIONS	12%	0	0	0	0
MAINTENANCE OPERATIONS	18%	0	0	0	
SAFETY	15%	0	0	0	
DEVELOPMENT RISK	10%	0	0	0	0
COST		0	0	0	0
	100%		0		
Weighted Score			0.00		0.

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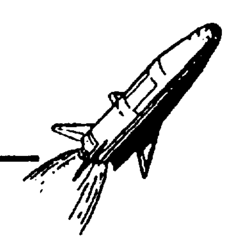
1A Options Received Best Scores Due To High Ranking In Nine Key Areas



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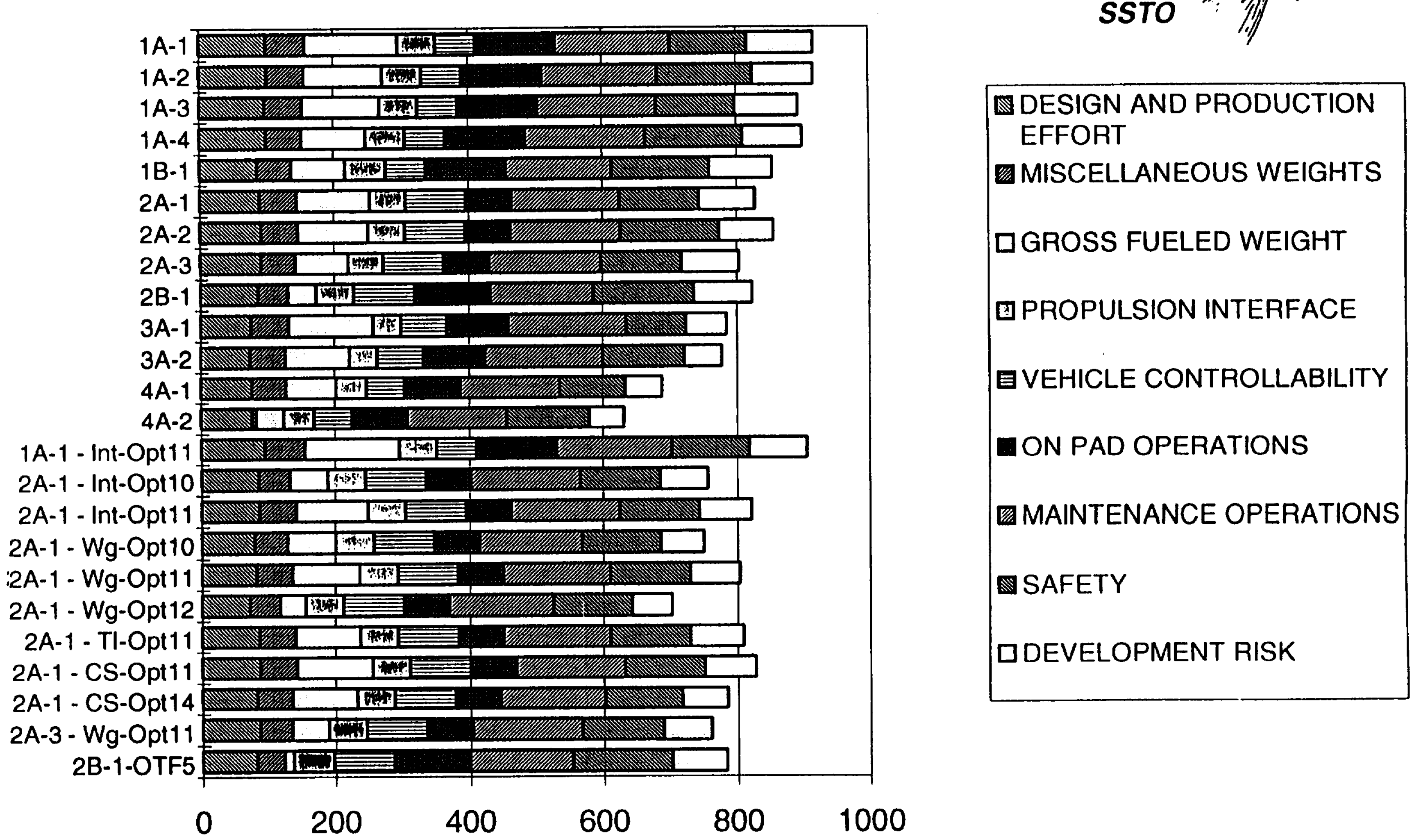

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1A Options Retained Best Scores Throughout Sensitivity Analysis

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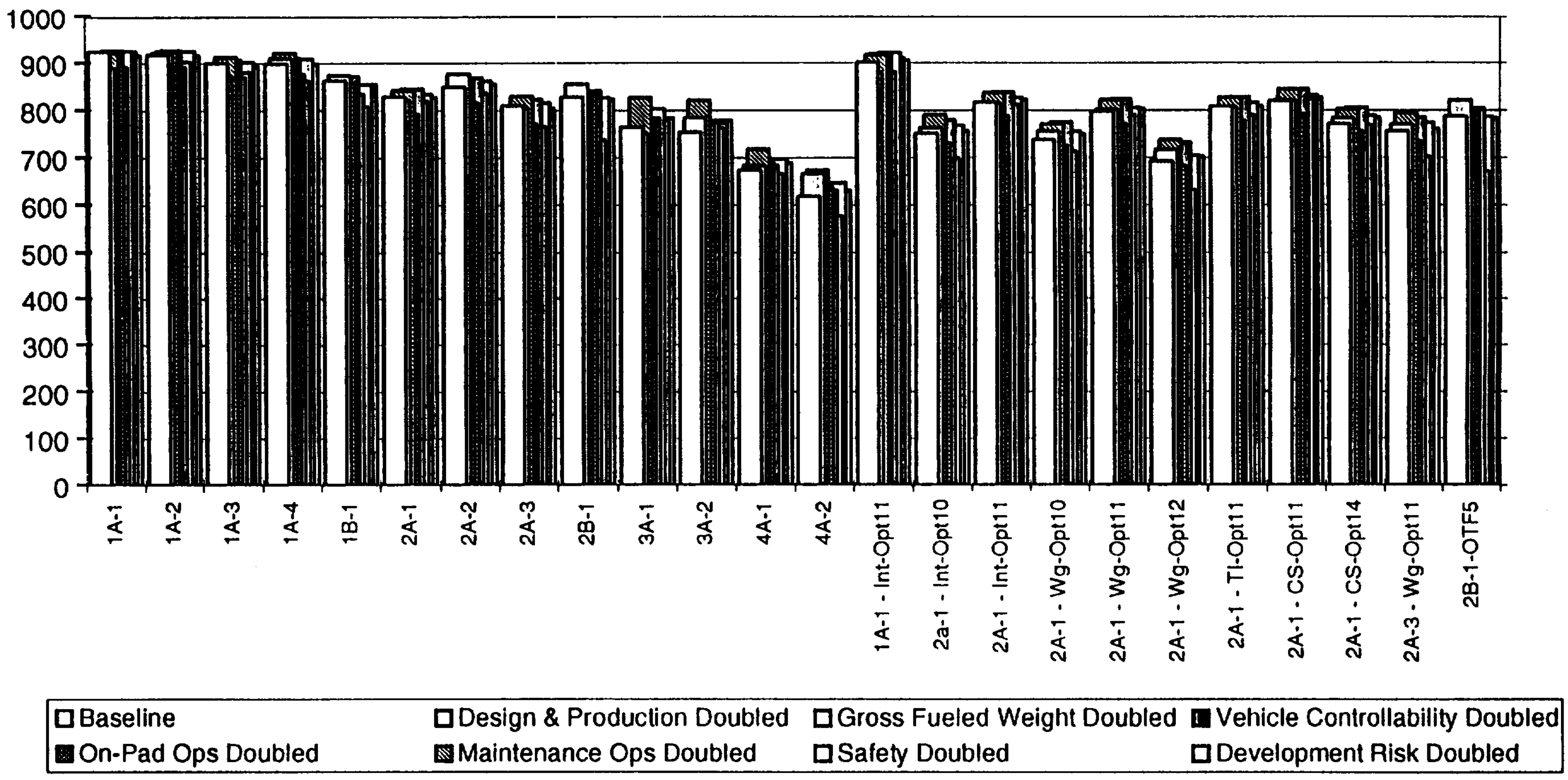

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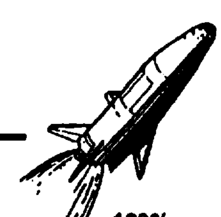
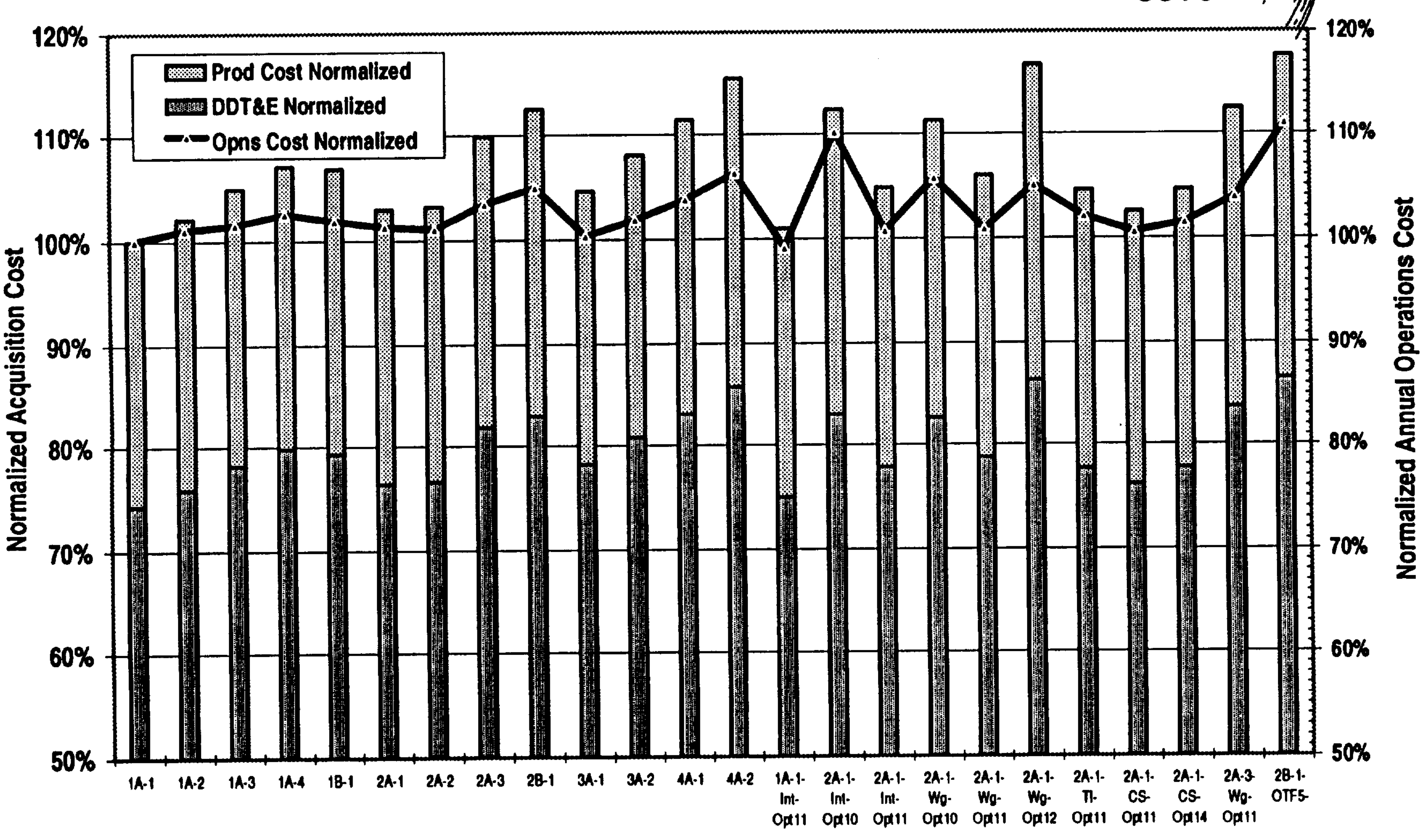
Parametric Costing Approach

Composite Trade Study
Selection
Process

Cost Estimates Favor 1A-1 But 2A-1 and 3A-1 Are Only Slightly Higher in Cost





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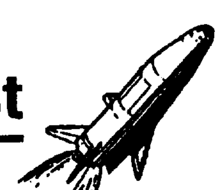
Cost Assessment Based on Total Program

<u>10.0 Total Program Cost</u> - Ranking by cost for each phase of the program provided using combination of parametrics and grass-roots assessments. ***Grass roots data based on best information now available using design engineers best estimates.***

- **Design and Development Cost**
- **Production Cost**
- **Operations Cost**
- **Life Cycle Cost**
- **Cost per Flight**

1A-1 Option Ranked Best For Lowest DDT&E Cost



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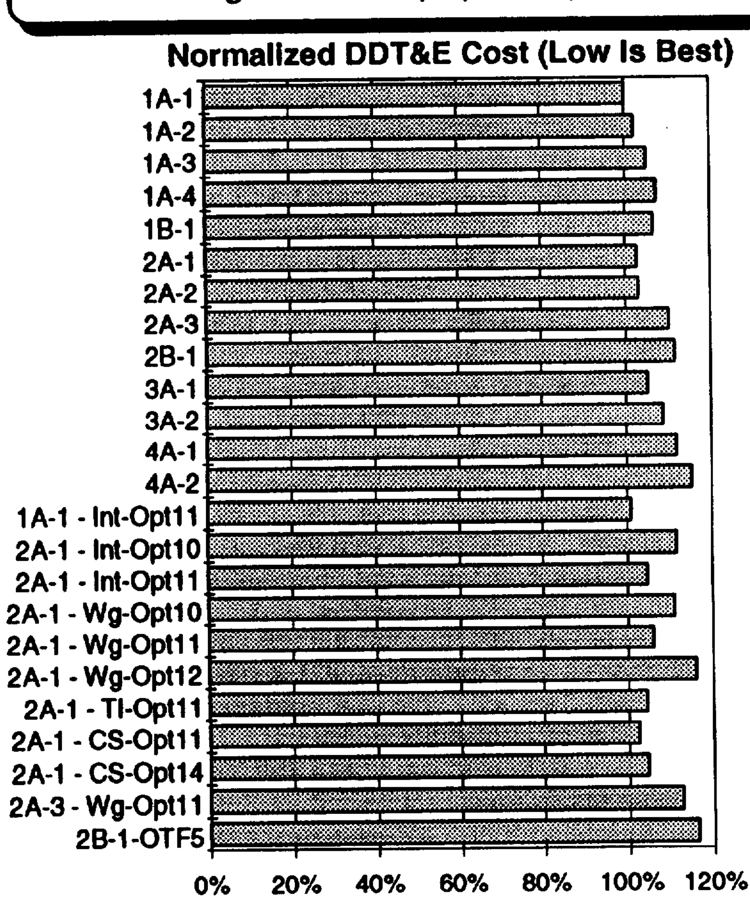
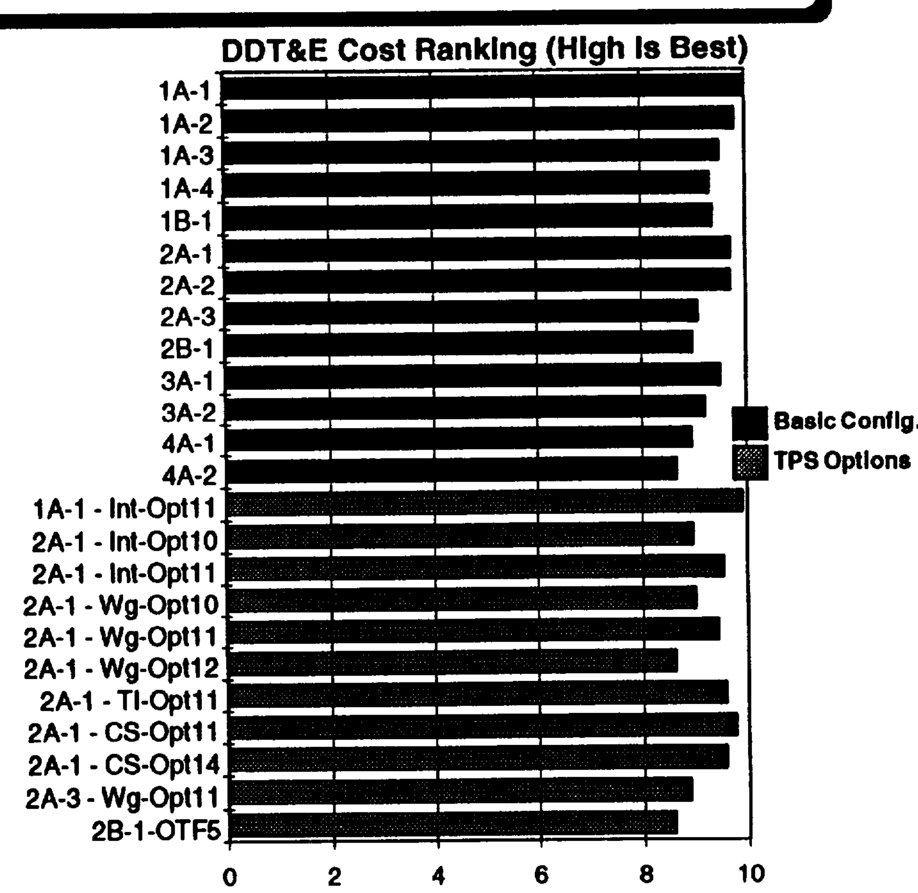
- ***10a. DDT & E Cost - (Quantitative Evaluation)*** *- The candidate vehicle options are compared on the basis of estimated total DDT&E system cost. The cost estimates are based on cost estimating relationships(CER's) which are complexity and weight driven.*





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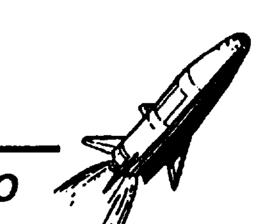
DDT & E Cost Used to Identify Preferred Configurations

SSTO

10.0 a. ***DDT & E Cost - (Quantitative Evaluation)*** **- The candidate vehicle options are compared on the basis of estimated total DDT&E system cost. The cost estimates are based on cost estimating relationships(CER's) which are complexity and weight driven.**

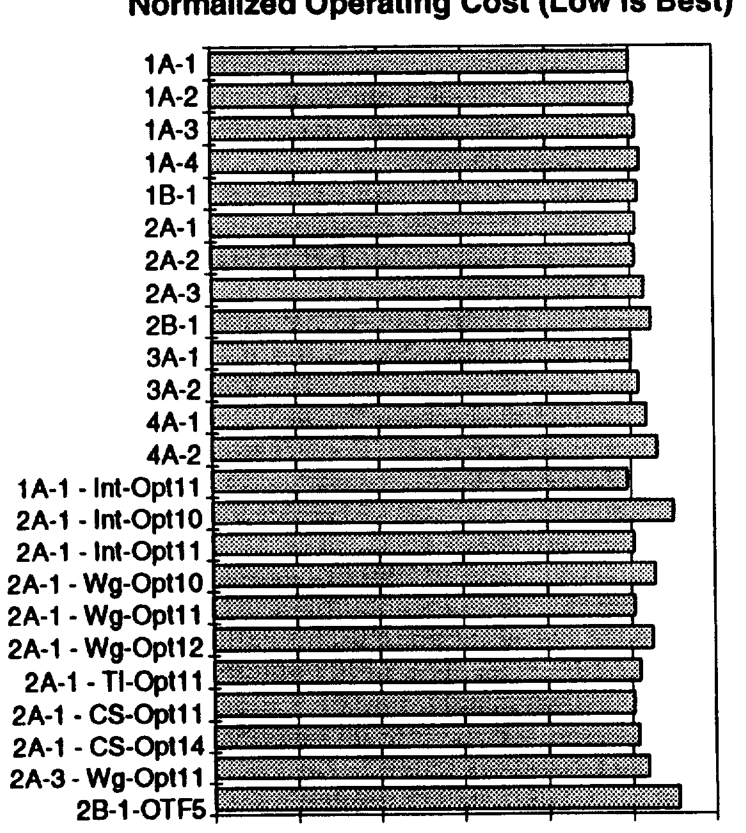
- **Rockwell SSTO Cost Model, based on Shuttle Orbiter Cost History, used to develop DDT & E costs.**
  - **Rockwell Sizing Program used to resize each candidate configuration based on the Reference Mission Requirements.**
  - **DDT & E cost for each configuration based on:**
    - **Weight sizing data**
    - **Complexity factors based on results of "Design and production complexity assessment".**

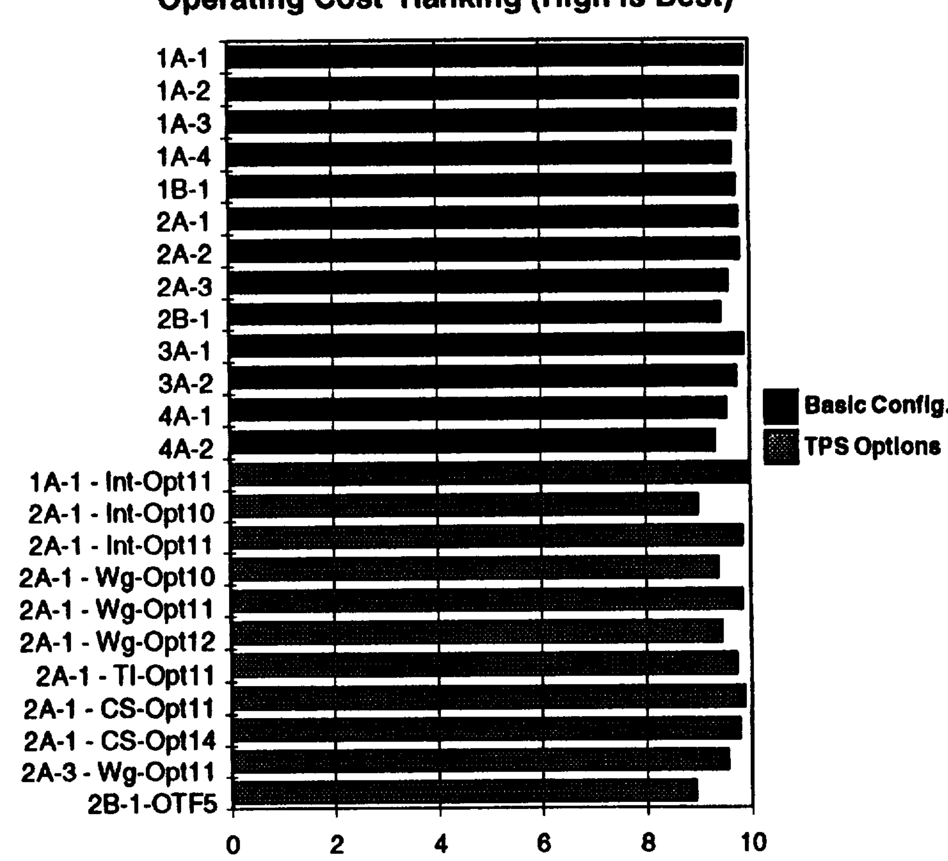
1A-1 Intertank Option Ranked Best For Lowest Operations Cost



SSTO

10b. Operations Cost- (Quantitative evaluation) - *The candidate vehicle options are compared on the basis of the cost of operations as determined from the operations hours and cost model.*





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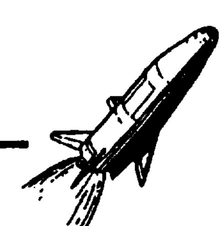
Operations Cost Used to Identify Preferred Configurations

SSTO

10.0 b. *Operations Cost- (Quantitative evaluation) - The candidate vehicle options are compared on the basis of the cost of operations as determined from the operations hours and cost model.*

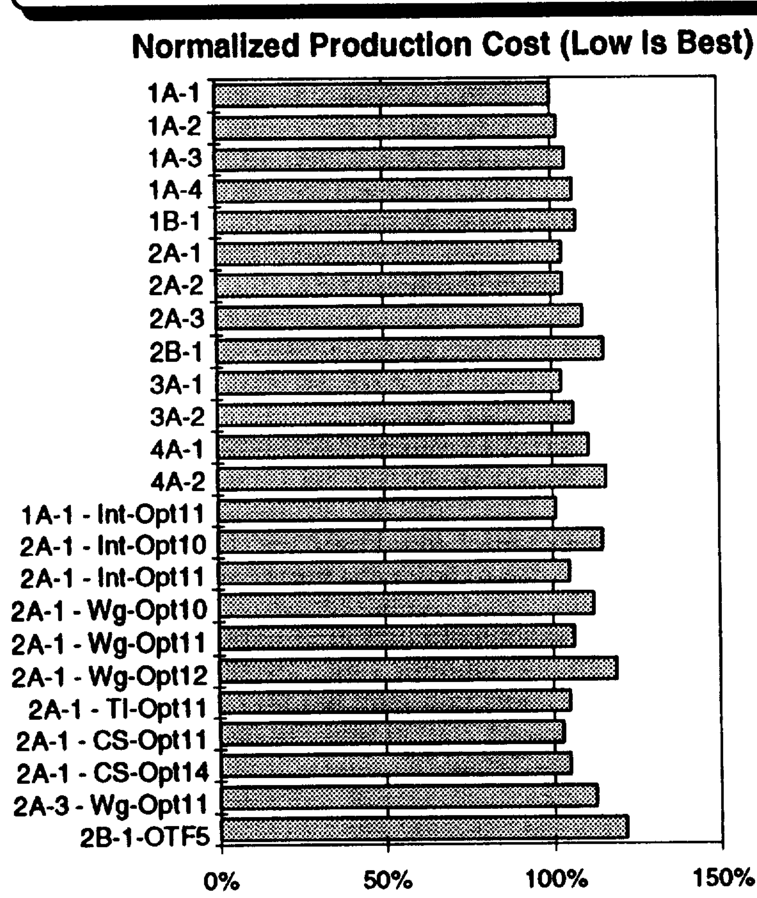
- Rockwell SSTO Operations Cost Model used to develop an estimate for the total operations cost for each vehicle option.
  - Rockwell Sizing Program used to resize each candidate configuration based on the Reference Mission Requirements.
  - Operation cost based on sizing data and adjustment of operation complexities for those subsystems directly impacted by design trade information.
    - TPS refurbishment based on acreage
    - Main Engines by estimated life, quantity per vehicle, and first unit cost.
    - Facilities by size

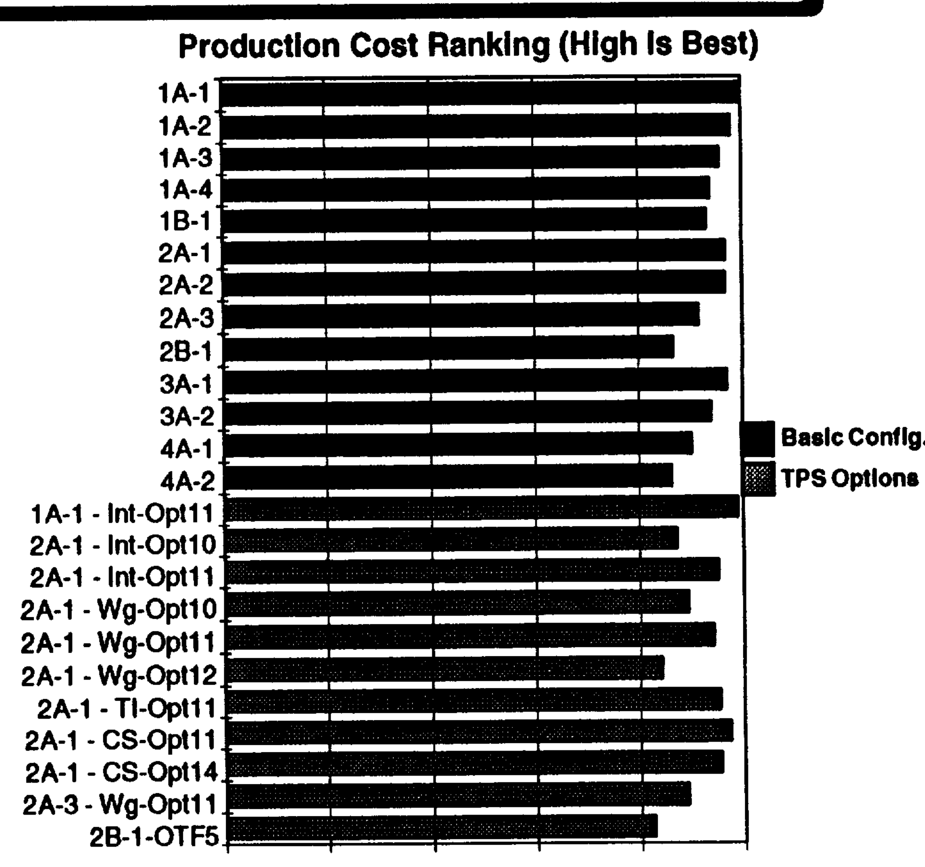
1A-1 Option Ranked Best For Lowest Production Cost For 3-Vehicle Fleet



SSTO

- ***10c. Production Cost (Quantitative evaluation)*** *- The candidate vehicle options are compared on the basis of the determined production cost for a 3-vehicle fleet.*





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Production Cost Used to Identify Preferred Configurations

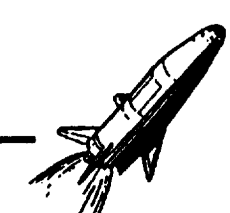
SSTO

<u>10.0 c. Production Cost - (Quantitative Evaluation)</u> - ***The candidate vehicle options are compared on the basis of the determined production cost for a 3-vehicle fleet.***

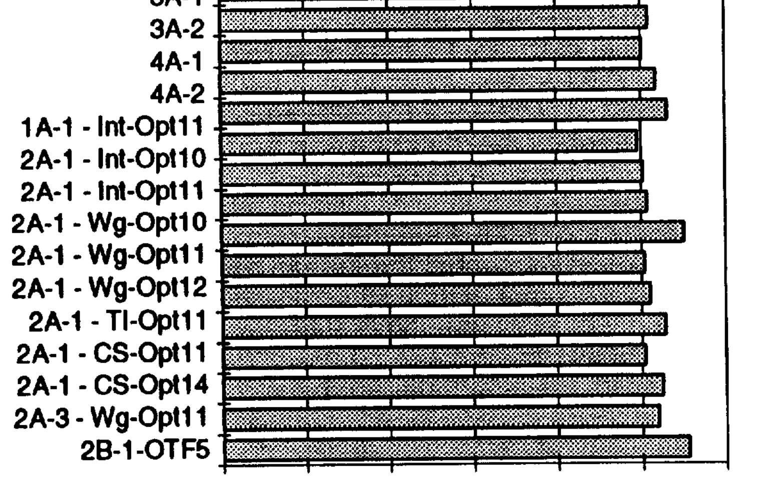
- **Rockwell SSTO Cost Model used to develop production cost estimates for each vehicle option.**
  - **Rockwell Sizing Program used to resize each candidate configuration based on the Reference Mission Requirements.**
  - **Production costs based on sizing data and adjustment of manufacturing complexities for those subsystems directly impacted by design trade information.**
  - **Complexity evaluation based on results of:**
    - **"1.0 Production complexity assessments" : more particularly, manufacture and producibility evaluations.**

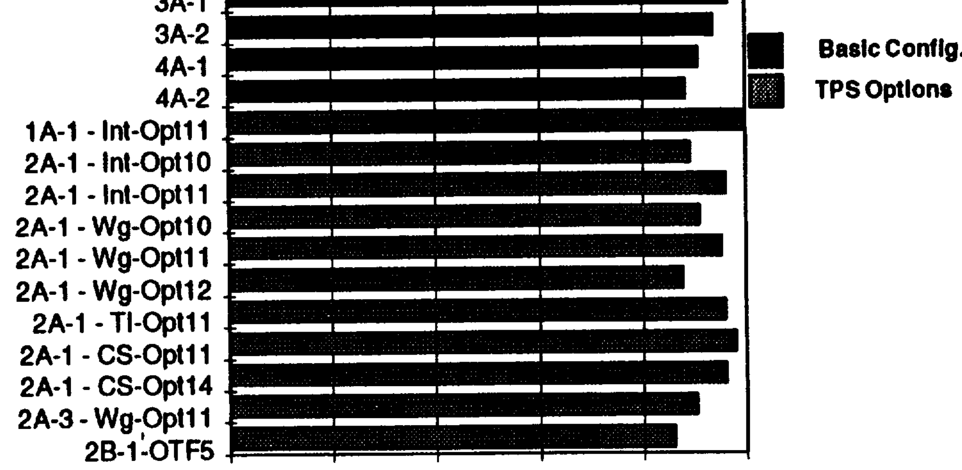
1A-1 Option Ranked Best For Lowest Life Cycle Cost

SSTO



- ***10d. Life Cycle Cost- (Quantitative Evaluation)*** *- The candidate vehicle options are compared on the basis of life cycle costs over 10-years of operations using 5% discounting.*





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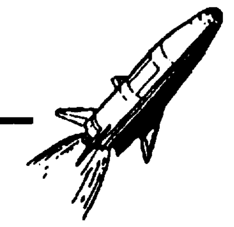
Life Cycle Cost - Approach

SSTO



10.0 d. *Life Cycle Cost- (Quantitative Evaluation) - The candidate vehicle options are compared on the basis of life cycle(DDT&E, Production, and Operations) costs over 10-years of operations using 5% discounting.*

- **Rockwell SSTO Cost Models used to develop the total life cycle cost for each vehicle option which is driven by complexity assessment and Sizing Data.**
  - **Rockwell Sizing Program used to resize each candidate configuration based on the Reference Mission Requirements.**
  - **Complexity evaluation based on design, analysis, tooling, and manufacturing complexity assessments.**

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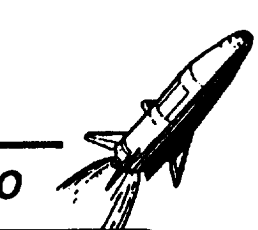
1A-1 Intertank Option Ranked Best For Lowest Cost Per Flight



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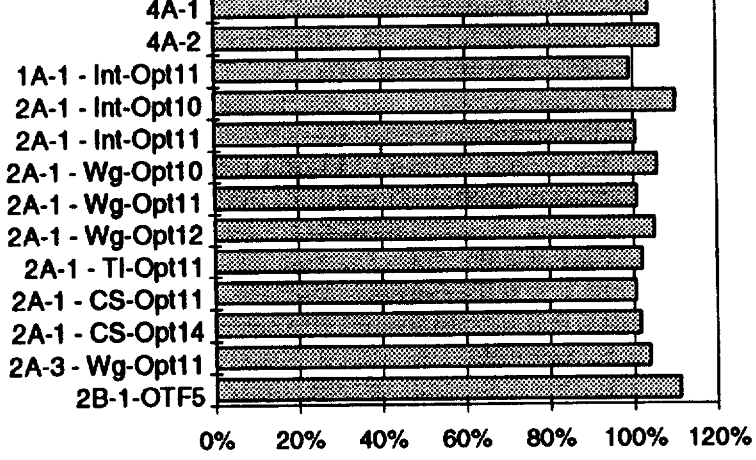
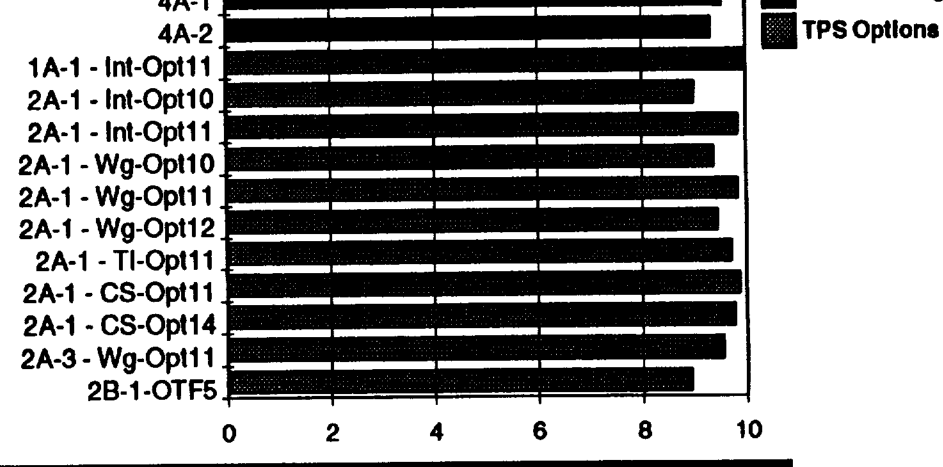
- ***10e. Cost per flight -Quantitative Evaluation)*** *- The candidate vehicle options are compared on the basis of forcasted annual operations cost and achieving a flight rate of 32 flghts per year.*





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Cost per Flight Based on 32 Flights Per Year

<u>10.0 e. Cost per Flight - (Quantitative Evaluation)</u> ***The candidate vehicle options are compared on the basis of forcasted annual operations cost and achieving a flight rate of 32 flghts per year.***

- **Operations Cost estimates are based on achieving 32 flights per year for each configuration based on manpower assessment for each option.**

NORMALIZED COST

BY

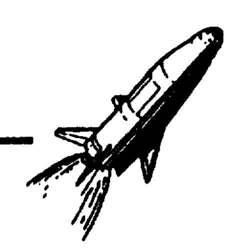
PROGRAM PHASE

FOR

CONFIGURATION

OPTIONS

Structures Complexity Approach



SSTO

- STANDARD PRACTICE:
  - USE HISTORICAL DATA AS BASIS FOR COST REFERENCE
  - USE JUDGMENT TO ADJUST PARAMETERS FOR DIFFERENCES IN DDT&E AND PRODUCTION.

- PROBLEM:
  - SSTO GRAPHITE-EPOXY STRUCTURAL DESIGNS WILL USE NEW AND DIFFERENT APPROACHES FROM PAST HISTORICAL DATA.
    - B2 COSTS DRIVEN BY "STEALTH" REQUIREMENTS(NoG)
    - B1 HISTORY BASED ON HAND LAY UP AND NON-PRECISION ASSEMBLY APPROACH.

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Structures Complexity Approach(Cont)

SSTO

- USE GRASS-ROOTS EVALUATION TO ESTABLISH BASELINE
- DEVELOP COMPLEXITY FACTORS FOR ALL OTHER CONFIGURATIONS
  - ENGINEERING:
    - NUMBER DRAWINGS
    - HOURS/DRAWING
  - TOOLING & FACILITIES
    - GRASS ROOTS FOR AUTOCLAVE & TOOLING
    - FACILITIES ESTIMATED
  - PRODUCTION:
    - TYPICALLY HRS/LB
    - MATERIAL $/LB

  - RATES: USE GENERAL RATES FOR ALL PARTIES

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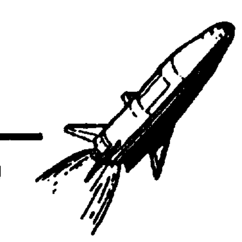
Costing Approach Has Both Weakness And Strengths



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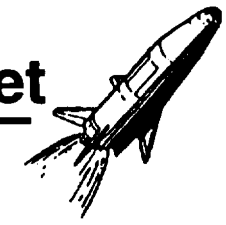
- WEAKNESSES:
  - "CLEAN SHEET" APPROACH IDENTIFIES ONLY WHAT IS KNOWN.
    - CLOSEOUTS AND PENETRATIONS NOT IDENTIFIED
    - APPROACH IS SUCCESS ORIENTED AND DOES NOT ALLOW FOR REDESIGNS
    - RATES ARE GENERIC
    - ENGINEERING ESTIMATES RELATIVE, NOT ABSOLUTE
- STRENGTHS
  - APPROACH MAXIMIZES KNOWLEDGE CAPTURE
    - ENGINEERING ABLE TO RELATE TO DRAWING COUNT
    - IDENTIFY DIFFERENCES IN COMPLEXITY
  - CONFIG 2A-1 USED AS REFERENCE
  - OTHER CONFIGURATIONS EVALUATED BASED ON DIFFERENCES FROM REFERENCE

Example: Design, Analysis, and Tooling Worksheet



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Includes Elevons		Basic Inputs	Basic Input/Drwg	Total Hours	Total Design & Dev Cost
1 Assembly Desc -->		Wing Option 2A-1			
2 Assembly Weight -->		15,987		Total Hours	Total Cost - D&D
3 Structural Design		Number Drawings	Hours Per Drawing	98,190	7,560,630
3.1a Complex Drawings		116	440	51,040	
3.1b Average Drawings		185	210	38,850	
3.1c Simple Drawings		83	100	8,300	
3.2 Analysis				98,190	7,560,630
3.2a Complex Drawings	1.0	116	440	51,040	
3.2b Average Drawings	1.0	185	210	38,850	
3.2c Simple Drawings	1.0	83	100	8,300	
3.3 Support(Wts, M&P, Producibility)		52%		102,118	7,863,055
3.4 Installation Drawings		8.1%		24,148	1,859,431
Total Design & Analysis				322,646	24,843,746
		Assembly Weight	Hours/lbs	Total Hours	Tooling Cost
5 Tooling		15,987	56	895,272	67,145,400

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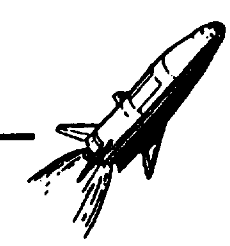
Example: First Unit and Support Cost Worksheet



SSTO

Includes Elevons

Assembly Desc --> Wing Option 2A-1

			Basic Inputs	Basic Input/Drwg	Total Hours	Total Design & Dev Cost
6.0	First Unit Cost					
6.1a	Fabrication Recurring			10	159,870	
6.1b	Assembly Recurring			5	79,935	
6.1c	Mfg Eng Non - Recur	% of Fab -->		25%	59,951	
6.1d	Mfg Eng - Recurring	% of Fab -->		5%	11,990	
6.1e	Inspection	% of Fab -->		10%	31,175	
6.1f	Supervision	% of Fab -->		10%	23,981	
	Fab Material	$/Lb ----->		250		3,996,750
5	Total Manufacturing (First Unit)				366,902	27,096,366
6	Support Costs % Eng					6,930,644
6a	Program Mgmt		7.6%	100%	52,406	3,825,611
6b	Quality Assurance		4.6%	100%	31,443	2,201,036
6c	Business & Subcont Mgmt		2.3%	100%	15,860	903,997
6d	Other		5.0%	100%	34,477	-
7	Test Quantity(Dedicated)		1.2	100%		32,516,640
8	Facilities & Equip Cost(K $'s)		Cost	Complexity		
8a	Manufacturing		34,000,000	100%		34,000,000
8b	Test			100%		
	Total DDT&E Cost					116,455,752

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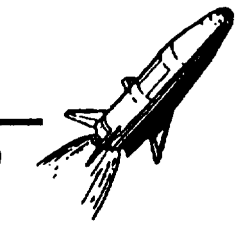
Complexity Results For Wing Assembly(Part 1)

SSTO



			1	2	3	4	5	6
			Wing & Wing Attach(Northrop/ Grumman)					
			1A-1/1A-2 1B-1	1A-3/1A-4	2A-1, 2A-2	2A-1 Opt #10	2A-1 Opt #11	2A-1 Opt #12
Assembly---->		Weighting Factors	LO2 Tank Aft	LO2 Tank Aft	LH2 Tank Aft	LH2 Tank Aft	LH2 Tank Aft	LH2 Tank Aft
Type Construction--->	Evaluation Parameter		Sandwich	Sandwich	Sandwich	Sandwich	Sandwich	Sandwich
Tank Location --->			LO Tank, Aft Skirt, Thrust Struc	Skirt, Thrust Struc Only	LH Tank, Aft Skirt, Thrust Struc	LH Tank, Aft Skirt, Thrust Struc	LH Tank, Aft Skirt, Thrust Struc	LH Tank, Aft Skirt, Thrust Struc
1	Weight For Assembly							
	Complexities(100 = Ref B/L) DDT&E(Non-Recurring)	100%						
2	Design Complexity	30%	110%	200%	100%	150%	140%	160%
3	Analysis Complexity	28%	110%	200%	100%	160%	140%	150%
4	Tooling Complexity	32%	100%	150%	100%	150%	120%	160%
5	Autoclave Complexity	5%	100%	120%	100%	140%	120%	100%
6	Attachment Complexity	5%	120%	150%	100%	140%	130%	140%
	Production(Recurring)	100%						
7	Manufacturing Complexity	65%	110%	150%	100%	160%	140%	180%
8	Interface Complexity	25%	110%	120%	100%	150%	130%	140%
9	Number of Parts	5%	100%	120%	100%	150%	120%	150%
10	Material Cost	5%	100%	120%	100%	130%	110%	200%
	Operations							
11	Testability		100%	120%	100%	140%	130%	140%
12	Accessibility		100%	100%	100%	120%	110%	120%
13	Maintainability		100%	120%	100%	150%	120%	140%
	Design & Develop Complexity		107%	178%	100%	152%	132%	153%
	TFU Complexity		109%	140%	100%	152%	135%	170%

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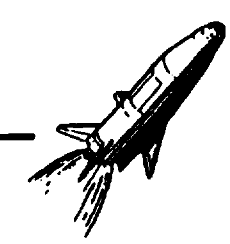
Complexity Results For Wing Assembly(Part 2)



SSTO

		7	8	9	10	11	12
		Wing & Wing Attach(Northrop/Grumman)					
		2A-3	2B-1	3A-1, 3A-2	3A-3	4A-1	4A-2
Assembly--->		LH2 Tank Aft	LH2 Tank Aft	LO2 Tank Aft	LO2 Tank Aft	Payload Bay Aft	Payload Bay Aft
Type Construction--->	Evaluation Parameter	Sandwich	Sandwich	Sandwich	Sandwich	Sandwich	Sandwich
Tank Location--->		Skirt, Thrust Struc Only	To Outer Fuselage Only	LO Tank, Aft Skirt, Thrust Struc	To Aft Skirt, Thrust Struc Only	To P/L Bay-Breadloaf Fuselage	Bay-Circular, Fuselage, Thrust
1	Weight For Assembly	Postponed			Postponed		
	Complexities(100 = Ref B/L) DDT&E(Non-Recurring)						
2	Design Complexity	180%	130%	110%	190%	90%	100%
3	Analysis Complexity	180%	140%	110%	190%	90%	100%
4	Tooling Complexity	140%	140%	120%	130%	90%	100%
5	Autoclave Complexity	120%	200%	100%	110%	100%	100%
6	Attachment Complexity	120%	150%	110%	120%	90%	100%
	Production(Recurring)						
7	Manufacturing Complexity	130%	180%	100%	140%	90%	100%
8	Interface Complexity	130%	100%	100%	140%	90%	100%
9	Number of Parts	110%	120%	90%	120%	110%	110%
10	Material Cost	110%	100%	100%	120%	90%	100%
	Operations						
11	Testability	120%	130%	100%	120%	90%	100%
12	Accessibility	120%	100%	100%	100%	90%	90%
13	Maintainability	120%	150%	100%	120%	90%	100%
	Design & Develop Complexity	161%	141%	113%	163%	91%	100%
	TFU Complexity	128%	153%	100%	138%	91%	101%

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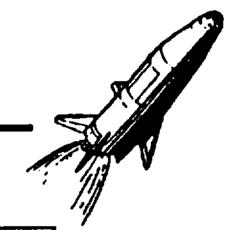
Complexity Results For Intertank Area

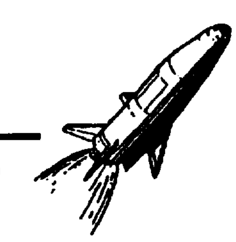
SSTO



No.	Evaluation Parameter	1	2	3	4	5	6	7	8	9
		Intertank Section(NoG)								
		1A, 1B	2A	2B	3A	4A-1	4A-2	1A-1 Int Opt 11	2A-1 Int Opt 10	2A-1 Int Opt 11
Assembly---->		Mid location	Mid location	Mid location + Wing Attach	fwd location + Canards	Aft Location	Aft Location	Mid location	Mid location	Mid location
Type Construction --->	Evaluation Parameter	Common Intertank & payload bay area	Common Intertank & payload bay area	Common Intertank & payload bay area	Payload bay area + canards - common blkhd	area - breadloaf fuselage - common blkhd	area - circular fuselage - common blkhd	Common Intertank & payload bay area	Common Intertank & payload bay area	Common Intertank & payload bay area
Tank Location --->		LH2 Tank Forward	LO2 Tank Forward	LO2 Tank Forward	LO2 Tank Forward	LH2 Tank Forward, LO2 Mid	LH2 Tank Forward, LO2 Mid	LH2 Tank Forward	LO2 Tank Forward	LO2 Tank Forward
1	Weight For Assembly									
	Complexities(100 = Ref B/L) DDT&E(Non-Recurring)									
2	Design Complexity	100%	100%	100%	130%	130%	140%	120%	140%	120%
3	Analysis Complexity	100%	100%	100%	120%	130%	140%	130%	150%	130%
4	Tooling Complexity	100%	100%	100%	120%	110%	110%	140%	150%	140%
5	Autoclave Complexity	100%	100%	100%	110%	120%	120%	160%	160%	160%
6	Attachment Complexity	100%	100%	100%	130%	120%	130%	150%	180%	150%
	Production(Recurring)									
7	Manufacturing Complexity	100%	100%	100%	120%	120%	130%	140%	150%	140%
8	Interface Complexity	100%	100%	100%	110%	110%	120%	120%	150%	120%
9	Number of Parts	100%	100%	100%	120%	110%	110%	110%	150%	110%
10	Material Cost	100%	100%	100%	110%	110%	110%	120%	150%	120%
	Operations									
11	Testability	100%	100%	100%	110%	110%	120%	120%	140%	120%
12	Accessibility	100%	100%	100%	120%	110%	120%	100%	120%	100%
13	Maintainability	100%	100%	100%	110%	110%	120%	130%	150%	130%
	Design & Develop Complexity	100%	100%	100%	123%	123%	129%	133%	149%	133%
	TFU Complexity	100%	100%	100%	117%	117%	126%	133%	150%	133%

Complexity Results For LH2 Tank

SSTO



			1	2	3	4	5	6	7	8	9	10
			Liquid Hydrogen Tank(Tulsa)									
	Operations Description		1A-1/1A-3	1A-2/1A-4	1B-1	2A-1/2A-3	2A-2	2B-1	3A-1	3A-2/3A-3	4A-1	4A-2
	Assembly——>	Weighting Factors	LH2 Tank Forward	LH2 Tank Forward	LH2 Tank Forward	LH2 Tank Aft	LH2 Tank Aft	LH2 Tank Aft	LH2 Tank Fwd-Com Blkhd	LH2 Tank Fwd-Com Blkhd	LH2 Tank Fwd-Com Blkhd	LH2 Tank Fwd-Com Blkhd
Type Construction —>	Evaluation Parameter		Integral-skin-stringer-frame	Integral-sandwich-frame	Non-Integral-sandwich	Integral-skin-stringer-frame	Integral-sandwich-frame	Non-Integral-sandwich	Integral-skin-stringer-frame	Integral-sandwich-frame	Integral-skin-stringer-frame	Integral-sandwich-frame
Tank Location —>			external	sandwich core	sandwich core	external	sandwich core	sandwich core	external	sandwich core	external	sandwich core
1	Weight For Assembly		8300	9800	6400	8900	11000	6400	8200	10000	9800	12200
	Complexities(100 = Reference B/L) DDT&E(Non-Recurring)	100%										
2	Design Complexity	30%	80%	60%	40%	100%	80%	35%	70%	60%	75%	65%
3	Analysis Complexity	28%	80%	80%	60%	100%	100%	55%	70%	70%	75%	75%
4	Tooling Complexity	32%	75%	55%	40%	100%	75%	35%	50%	35%	55%	40%
5	Autoclave Complexity	5%	106%	106%	106%	100%	100%	100%	115%	115%	130%	130%
6	Attachment Complexity	5%	80%	50%	40%	100%	80%	40%	100%	70%	100%	70%
	Production(Recurring)	100%										
7	Manufacturing Complexity	65%	100%	75%	70%	100%	80%	65%	80%	65%	85%	70%
8	Interface Complexity	25%	70%	70%	50%	100%	100%	50%	90%	90%	90%	90%
9	Number of Parts	5%	80%	50%	50%	100%	70%	50%	70%	50%	75%	55%
10	Material Cost	5%	110%	100%	75%	100%	90%	70%	90%	80%	95%	85%
	Operations											
11	Testability		90%	100%	80%	100%	110%	90%	100%	110%	100%	110%
12	Accessibility		100%	100%	150%	100%	100%	150%	100%	100%	100%	100%
13	Maintainability		90%	110%	120%	100%	120%	120%	110%	120%	110%	120%
	Design & Develop Complexity		80%	66%	49%	100%	85%	44%	67%	58%	73%	63%
	TFU Complexity		92%	74%	64%	100%	85%	61%	83%	71%	86%	75%

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Complexity Results For Thrust Structure

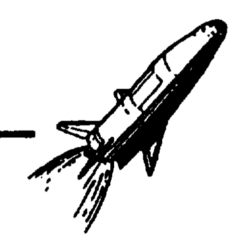
SSTO

			1	2	3
			Thrust Structure-Tulsa		
			1, 2, 3A	4A-1	4A-2
Assembly--->		Weighting Factors	Aft Skirt Interface	Aft Skirt Interface	Aft Skirt Interface
Type Construction--->	Evaluation Parameter		Conical Shell - longeron frame	Truss Construction	Conical Shell - longeron frame
Tank Location --->			LO Tank, Aft Skirt, Thrust Struc	LO Tank, Aft Skirt, Thrust Struc	To Aft Skirt, Thrust Struc Only
1	Weight For Assembly				
	Complexities(100 = Reference B/L) DDT&E(Non-Recurring)	100%			
2	Design Complexity	30%	100%	130%	110%
3	Analysis Complexity	28%	100%	130%	110%
4	Tooling Complexity	32%	100%	80%	100%
5	Autoclave Complexity	5%	100%	80%	100%
6	Attachment Complexity	5%	100%	135%	100%
	Production(Recurring)	100%			
7	Manufacturing Complexity	65%	100%	130%	110%
8	Interface Complexity	25%	100%	135%	100%
9	Number of Parts	5%	100%	140%	100%
10	Material Cost	5%	100%	91%	100%
	Operations				
11	Testability		100%	120%	100%
12	Accessibility		110%	100%	110%
13	Maintainability		100%	100%	100%
	Design & Develop Complexity		100%	112%	106%
	TFU Complexity		100%	130%	107%

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Complexity Results For LO2 Tank

SSTO



	Evaluation Parameter	Weighting Factors	1	2	3	4	5	6
			Liquid Oxygen Tank(SSD)					
			1A-1/1A-2 1B-1	1A-3/1A-4	2A, 2B	3A-1, 3A-2	3A-3	4A-1, 4A-2
Assembly—>			LO2 Tank Aft	LO2 Tank Aft	LO2 Tank Forward	LO2 Tank Aft	LO2 Tank Aft	LO2 Tank Mid
Type Construction—>			Integral-skin-stringer-frame	Integral-skin-stringer-frame	Integral-skin-stringer-frame	Integral-skin-stringer-frame	Integral-skin-stringer-frame	Integral-skin-stringer-frame
Tank Location —>			Wing Attached	Wing Not Attached	Wing Not Attached	Wing Attached Common Bulkhead	Wing Not Attached Common Bulkhead	Wing Attached Common Bulkhead
1	Weight For Assembly							
	Complexities(100 = Reference B/L)							
	DDT&E(Non-Recurring)	100%						
2	Design Complexity	30%	200%	100%	100%	300%	200%	300%
3	Analysis Complexity	28%	200%	100%	100%	300%	200%	300%
4	Tooling Complexity	32%	100%	100%	100%	200%	200%	200%
5	Autoclave Complexity	5%	100%	100%	100%	100%	100%	100%
6	Attachment Complexity	5%	125%	100%	100%	300%	250%	300%
	Production(Recurring)	100%						
7	Manufacturing Complexity	65%	125%	100%	100%	200%	200%	200%
8	Interface Complexity	25%	125%	100%	100%	300%	250%	300%
9	Number of Parts	5%	100%	100%	100%	100%	100%	100%
10	Material Cost	5%	100%	100%	100%	100%	100%	100%
	Operations							
11	Testability		200%	100%	100%	300%	250%	300%
12	Accessibility		100%	100%	100%	150%	150%	150%
13	Maintainability		150%	100%	100%	200%	200%	200%
	Design & Develop Complexity		159%	100%	100%	258%	198%	258%
	TFU Complexity		123%	100%	100%	215%	203%	215%

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APPLICATION OF COMPLEXITY EVALUATIONS

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Acquisition Cost Model Parameters

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- DESIGN AND DEVELOPMENT DRIVEN LINEARLY BY D&D FACTOR
- TEST HARDWARE DRIVEN BY NUMBER OF DEDICATED TEST UNITS AND FIRST UNIT COST ESTIMATE
- RECURRING COST DRIVEN BY:
  - TFU COST
  - NUMBER OF UNITS PER SHIPSET
  - LEARNING CURVE
- SUPPORT COSTS DRIVEN BY FACTORS x HARDWARE COSTS
  - FACILITIES DRIVEN BY VEHICLE FIRST UNIT COST AND VEHICLE DRY WEIGHT
  - SUPPORT EQUIPMENT DRIVEN BY VEHICLE FIRST UNIT COST AND VEHICLE DRY WEIGHT
  - SYSTEMS COST DRIVEN BY VEHICLE WEIGHT AND FIRST UNIT COST.

Programmatic Costs Assumptions

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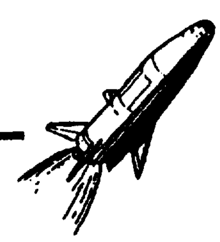
- COSTS ESTIMATED IN 1995 DOLLARS, THEN NORMALIZED
- ACQUISITION COST FOR 3-VEHICLE FLEET
- OPERATIONS COST ANNUAL COST/YEAR RATE
  - 32 FLIGHTS / YEAR USED AS BASE
  - COST DRIVEN BY:
    - VEHICLE DRY WEIGHT
    - ACREAGE OF TPS
    - NUMBER OF ENGINES
    - VEHICLE SUBSYSTEM FIRST UNIT vs. ORBITER

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Example: Level of Model Details And Content



RD-704 Triprop Engines 25 K PL to SSF

WBS #	WBS DESCRIPTION	Total Weight	Design/ Dev Cost	Tooling/ STE & Fac Cost	Test Hard Cost	DDT&E Cost	First Shipset Cost	Cost Thru 1st Flight	Product Cost Flts 2-3	Total Program Cost
	TOTAL PROGRAM									
	Other Costs									
	Reserves									
	HQ Taxes									
	Program Support									
	Facilities									
1.0	Price to the Government									
1A	Total Contractor Cost									
1.2	Support Costs									
1.1	Project Management									
1.2	Systems Engrg & Integration									
1.4	Integration, Assembly & Checkout									
1.5	Veh Sys Integ & Test									
1.6	Support Equipment									
1.7	Software (Gmd & Flt)									
1.3	Flight Vehicle									
1.3.1	Structures									
1.3.1.1	Structures - Aero Surfaces									
1.3.1.1.1	Wing Control Surfaces									
1.3.1.1.2	Vertical Tail									
1.3.1.1.3	Canard									
1.3.1.1.4	Body Flap (Gr Comp)									
1.3.1.1.5	Speed Brake									
1.3.1.2	Primary Fuselage									
1.3.1.2.1	Forward Fuselage									
1.3.1.2.2	Inter Tank									
1.3.1.2.3	Payload Provisions									
1.3.1.2.4	LH2 Tank(Includes Autoclave &									
1.3.1.2.5	LOX Tank									
1.3.1.2.6	RP Tank									
1.3.1.2.7	Outer Shell(LH2 Non-Integral Ta									
1.3.1.2.8	Body Fairings									
1.3.1.2.9	Vert Tail Fairing & Attach Struct									
1.3.1.2.9	Thrust Structure									
1.3.1.5	Thermal Protection Sys									
1.3.1.5.1	ACC									
1.3.1.5.2	AETB									
1.3.1.5.3	AFRSI									
1.3.1.5.4	TABI									
1.3.1.5.4	Carbon Silicone									
1.3.1.5.5	Cryo Insulation									
1.3.1.6	Miscellaneous									
1.3.1.6.1	Purge Vent & Drain									
1.3.1.6.3	Thermal Control(Internal Insul.)									
1.3.2	Propulsion System									
1.3.2.1	Main Engines(RD-704)									
1.3.2.2	Engine Ancillary System									
1.3.2.3	Propellant & Pressurization Sys									
1.3.2.4	OMS Thruster System									
1.3.2.5	Reaction Control System									

EXAMPLE: LEVEL OF MODEL DETAIL

z	SSTO Operations	Fixed Annual	Variable Annual	Forecast Annual Cost ('95 M$'s)
3.0	SSTO Operations			
3.1	Management			
3.1.1	Program Management			
3.1.2	Systems Eng & Integ			
3.1.3	Engineering Support			
3.4	Operations			
3.4.1	Vehicle Operations			
3.4.1.1	Consolidated Control Center Operations			
3.4.1.1.1	Ground & Flight Opns Support			
3.4.1.1.2	Facility & Supt. Equip. Maintenance			
3.4.1.1.3	Facility & Supt. Equip. Modifications			
3.4.1.1.4	Consummables			
3.4.1.2	Maintenance Facility Operations			
3.4.1.2.1	Vehicle Maintenance & Servicing			
3.4.1.2.2	Facility & Supt. Equip. Maintenance			
3.4.1.2.3	Facility & Supt. Equip. Modifications			
3.4.1.2.4	Consummables			
3.4.1.3	Pad Operations			
3.4.1.3.1	Launch Operations			
3.4.1.3.2	Facility & Supt. Equip. Maintenance			
3.4.1.3.3	Facility & Supt. Equip. Modifications			
3.4.1.3.4	Propellants & Gases			
3.4.1.4	Mission Operations			
3.4.1.4.1	Mission Planning & Support			
3.4.1.4.2	Facility & Supt. Equip. Maintenance			
3.4.1.4.3	Facility & Supt. Equip. Modifications			
3.4.1.4.4	Consummables			
3.4.1.5	Landing Operations			
3.4.1.5.1	Vehicle Deservicing & Transport			
3.4.1.5.2	Facility & Supt. Equip. Maintenance			
3.4.1.5.3	Facility & Supt. Equip. Modifications			
3.4.1.5.4	Consummables			
3.4.2	Logistics Operations			
3.4.2.1	Planning & Support			
3.4.2.2	Provisioning			
3.4.2.3	Repair and Overhaul			
3.4.2.4	Site Maintenance			
3.4.2.5	Training			
3.4.2.6	Receiving & Storage			
3.4.2.7	Data			
3.4.2.8	Facility & Equip. Maintenance			
3.4.2.9	Facility & Equip. Modifications			
3.4.2.10	Consummables			
3.4.3	Payload Operations			
3.4.3.1	Payload Services Planning & Support(BL)			
3.4.3.2	Off-line Payload Processing			
3.4.3.3	Payload Special Flight Support Equipment			
3.4.3.4	Upper Stages & Provisions			
3.4.3.5	Mission Support - Special			

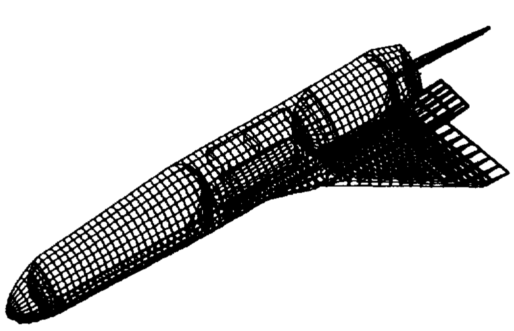
EXAMPLE : LEVEL OF MODEL DETAIL

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

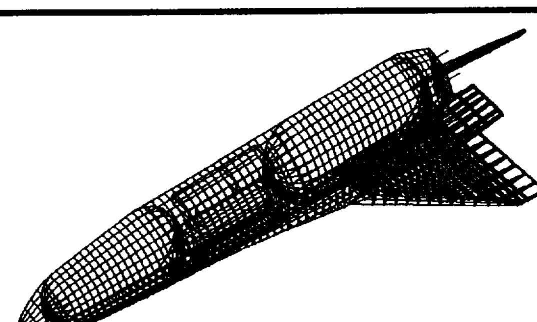
Finite Element Model Analysis

Finite Element Models Define Loads For All, Structural Arrangement Options

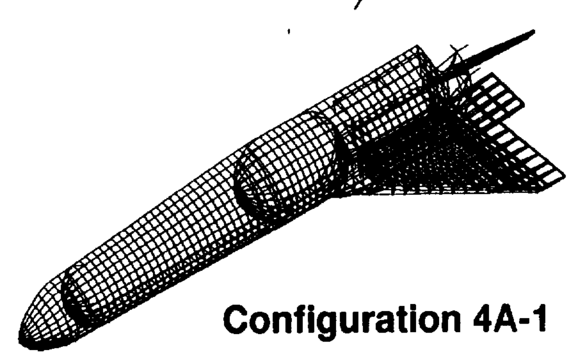
SSTO



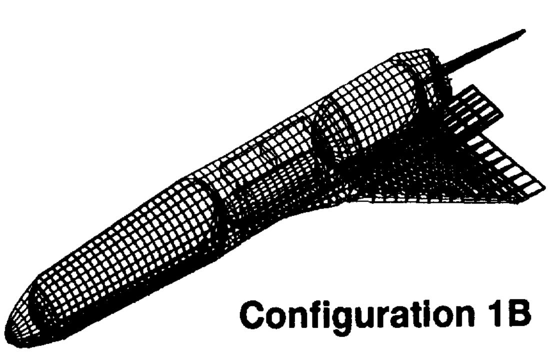
Configuration 1A, 1A-WD



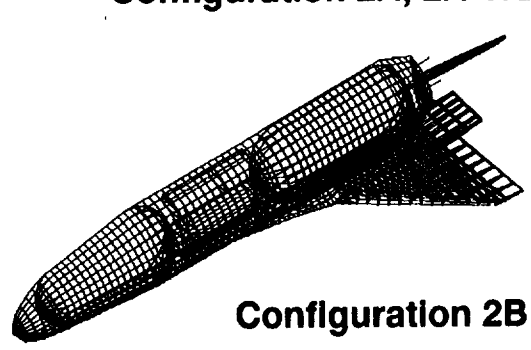
Configuration 2A, 2A-WD



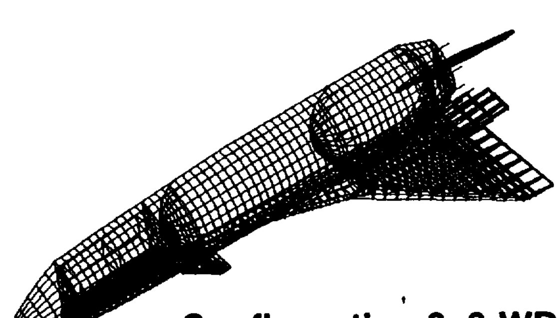
Configuration 4A-1



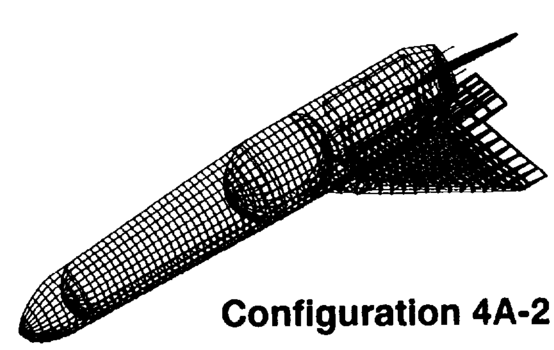
Configuration 1B



Configuration 2B



Configuration 3, 3-WD

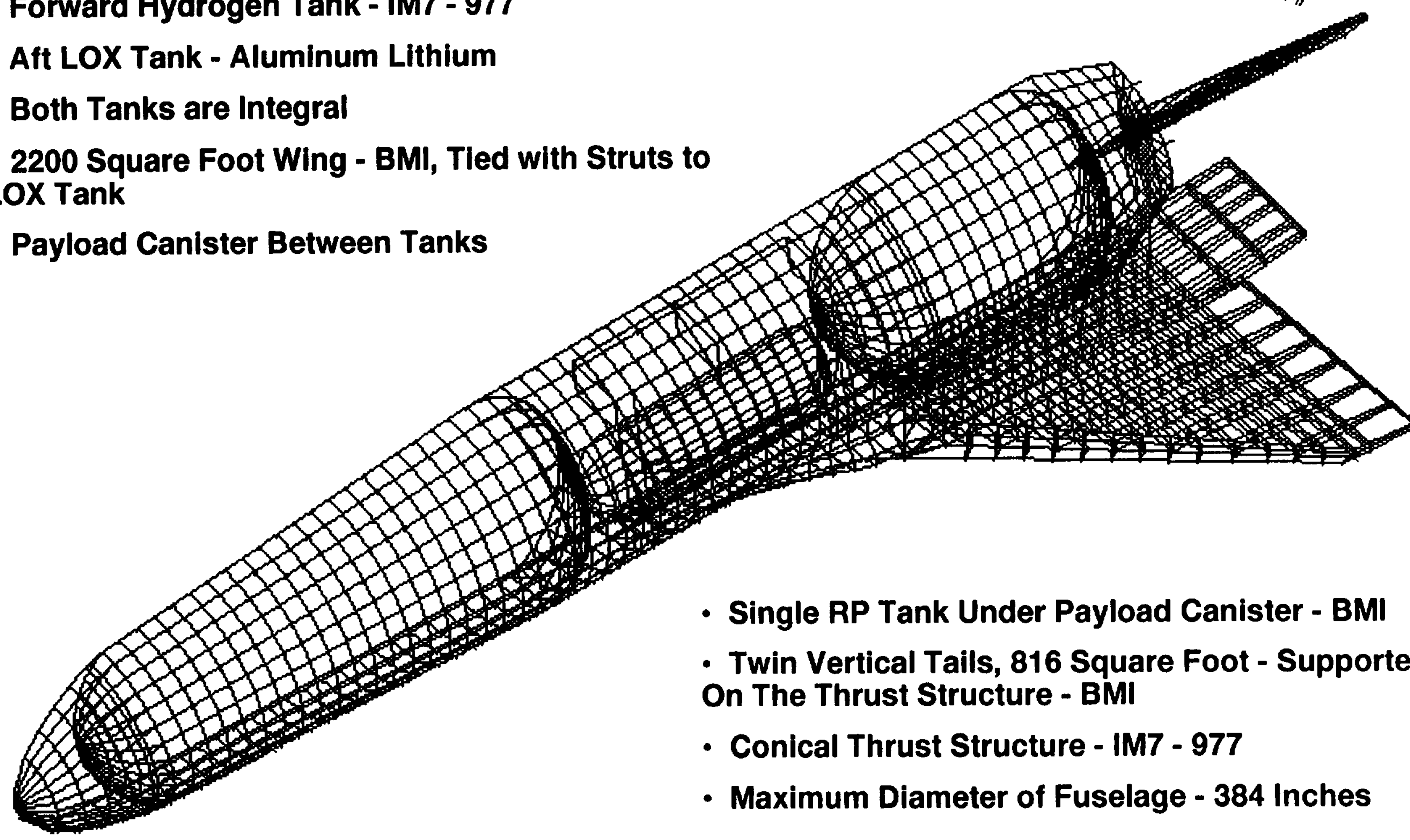


Configuration 4A-2

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Configuration 1A Finite Element Model

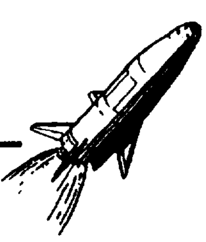
- Forward Hydrogen Tank - IM7 - 977
- Aft LOX Tank - Aluminum Lithium
- Both Tanks are Integral
- 2200 Square Foot Wing - BMI, Tied with Struts to LOX Tank
- Payload Canister Between Tanks



- Single RP Tank Under Payload Canister - BMI
- Twin Vertical Tails, 816 Square Foot - Supported On The Thrust Structure - BMI
- Conical Thrust Structure - IM7 - 977
- Maximum Diameter of Fuselage - 384 Inches

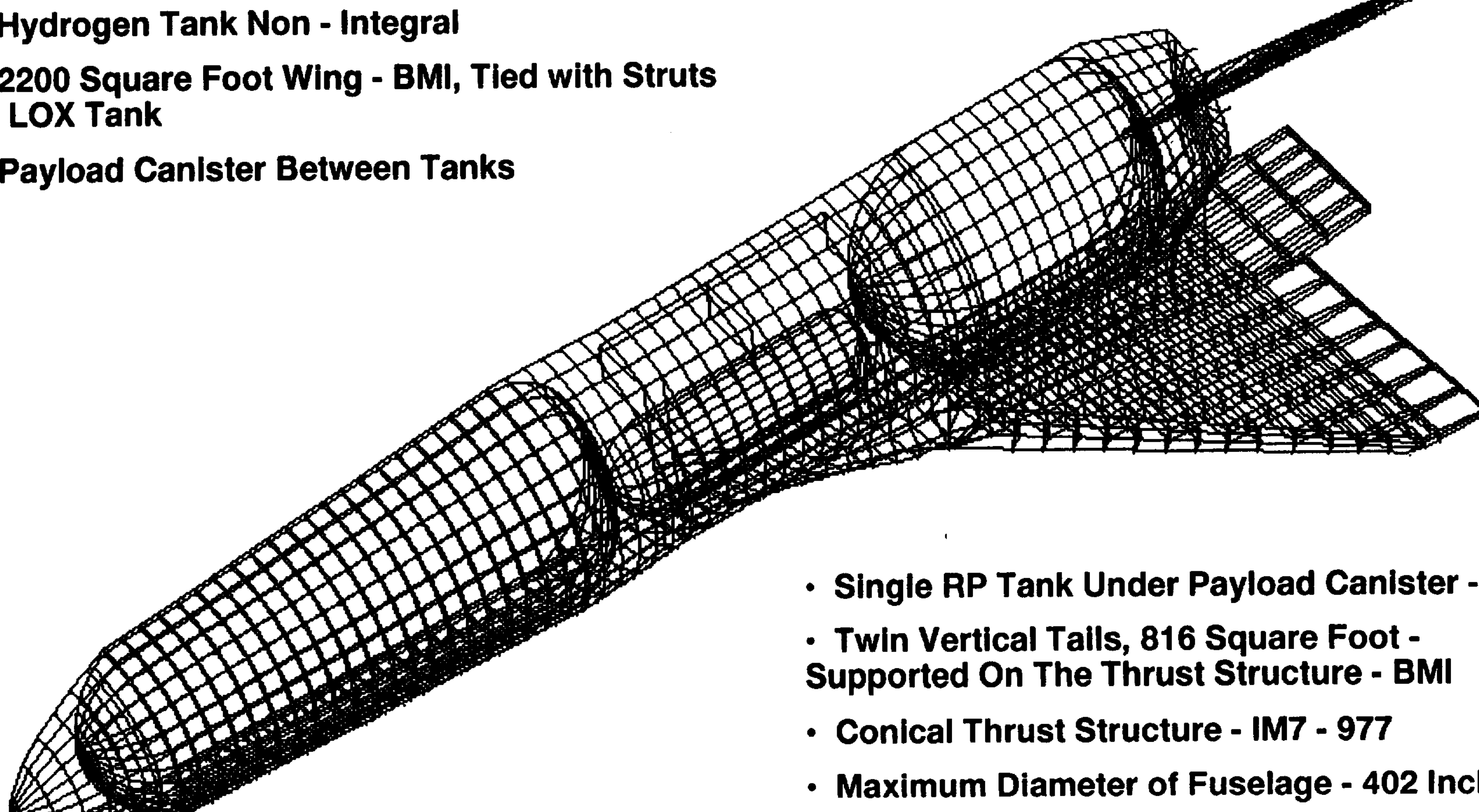
NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Configuration 1B Finite Element Model



SSTO

- Forward Hydrogen Tank - IM7 - 977
- Aft LOX Tank - Aluminum Lithium
- Hydrogen Tank Non - Integral
- 2200 Square Foot Wing - BMI, Tied with Struts to LOX Tank
- Payload Canister Between Tanks



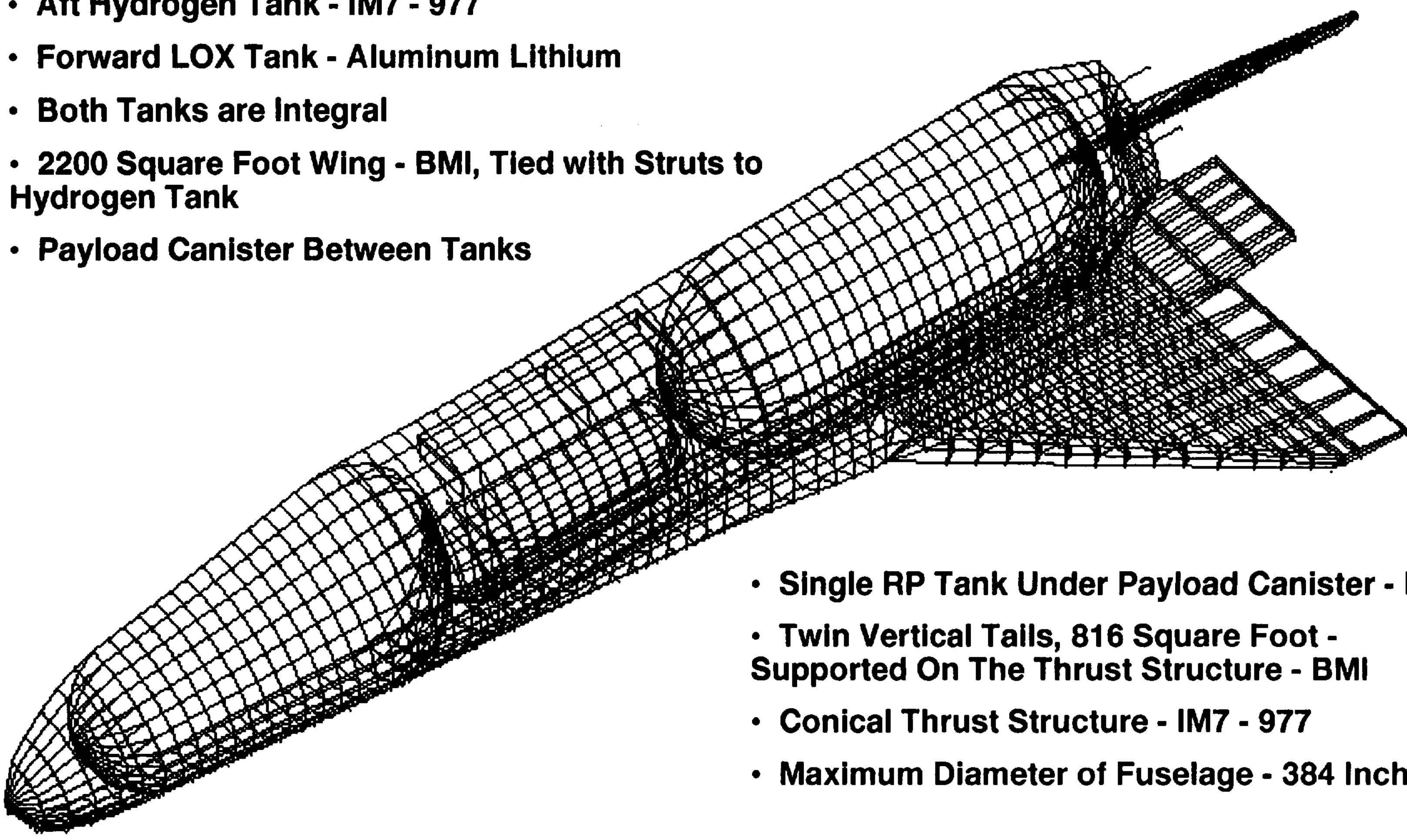
- Single RP Tank Under Payload Canister - BMI
- Twin Vertical Tails, 816 Square Foot - Supported On The Thrust Structure - BMI
- Conical Thrust Structure - IM7 - 977
- Maximum Diameter of Fuselage - 402 Inches

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Configuration 2A Finite Element Model

SSTO

- **Aft Hydrogen Tank - IM7 - 977**
- **Forward LOX Tank - Aluminum Lithium**
- **Both Tanks are Integral**
- **2200 Square Foot Wing - BMI, Tied with Struts to Hydrogen Tank**
- **Payload Canister Between Tanks**



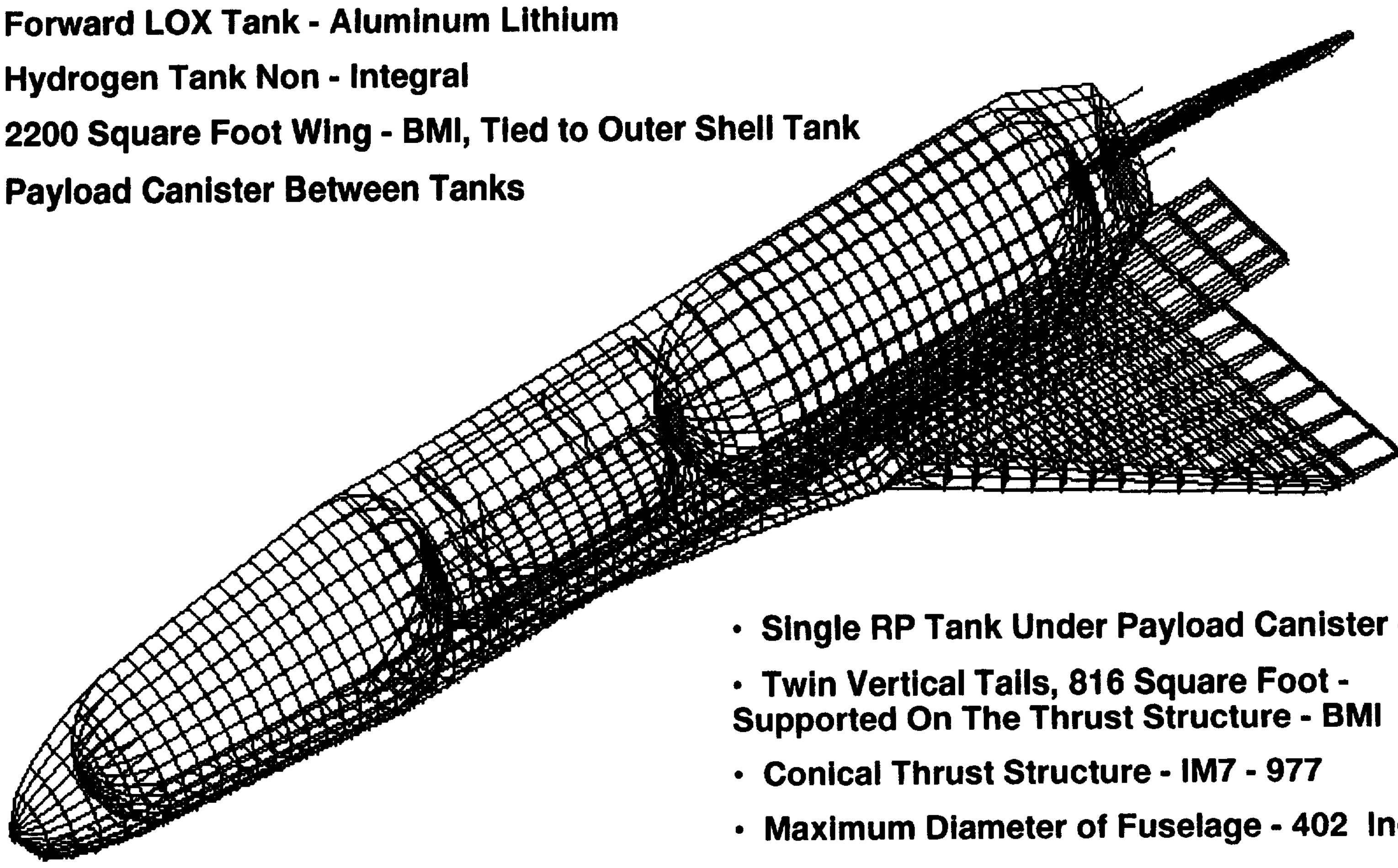
- **Single RP Tank Under Payload Canister - BMI**
- **Twin Vertical Tails, 816 Square Foot - Supported On The Thrust Structure - BMI**
- **Conical Thrust Structure - IM7 - 977**
- **Maximum Diameter of Fuselage - 384 Inches**

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Configuration 2B Finite Element Model

SSTO

- Aft Hydrogen Tank - IM7 - 977
- Forward LOX Tank - Aluminum Lithium
- Hydrogen Tank Non - Integral
- 2200 Square Foot Wing - BMI, Tied to Outer Shell Tank
- Payload Canister Between Tanks



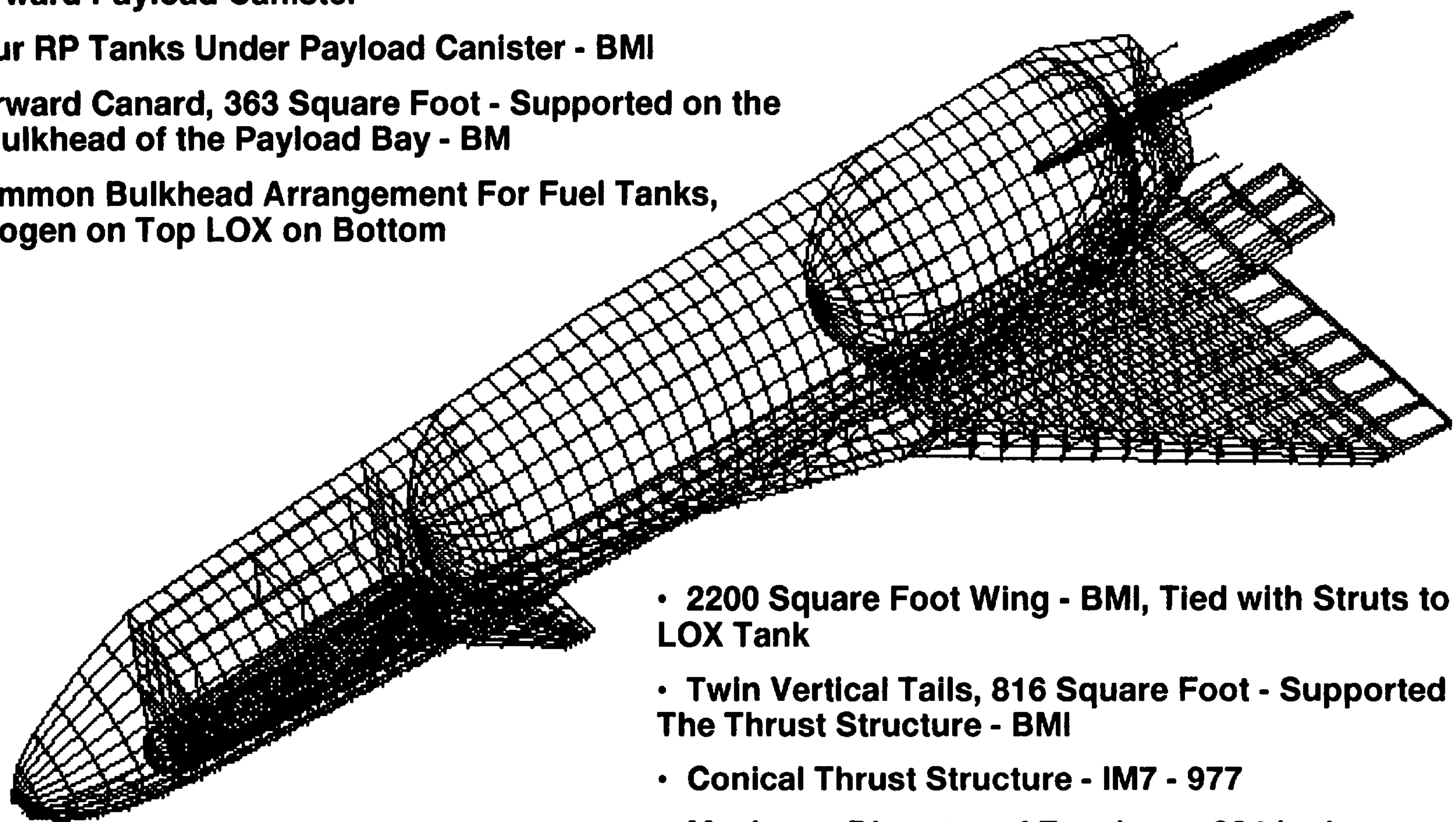
- Single RP Tank Under Payload Canister - BMI
- Twin Vertical Tails, 816 Square Foot - Supported On The Thrust Structure - BMI
- Conical Thrust Structure - IM7 - 977
- Maximum Diameter of Fuselage - 402 Inches

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Configuration 3 Finite Element Model

SSTO

- Forward Payload Bay - BMI
- Forward Payload Canister
- Four RP Tanks Under Payload Canister - BMI
- Forward Canard, 363 Square Foot - Supported on the Aft Bulkhead of the Payload Bay - BM
- Common Bulkhead Arrangement For Fuel Tanks, Hydrogen on Top LOX on Bottom



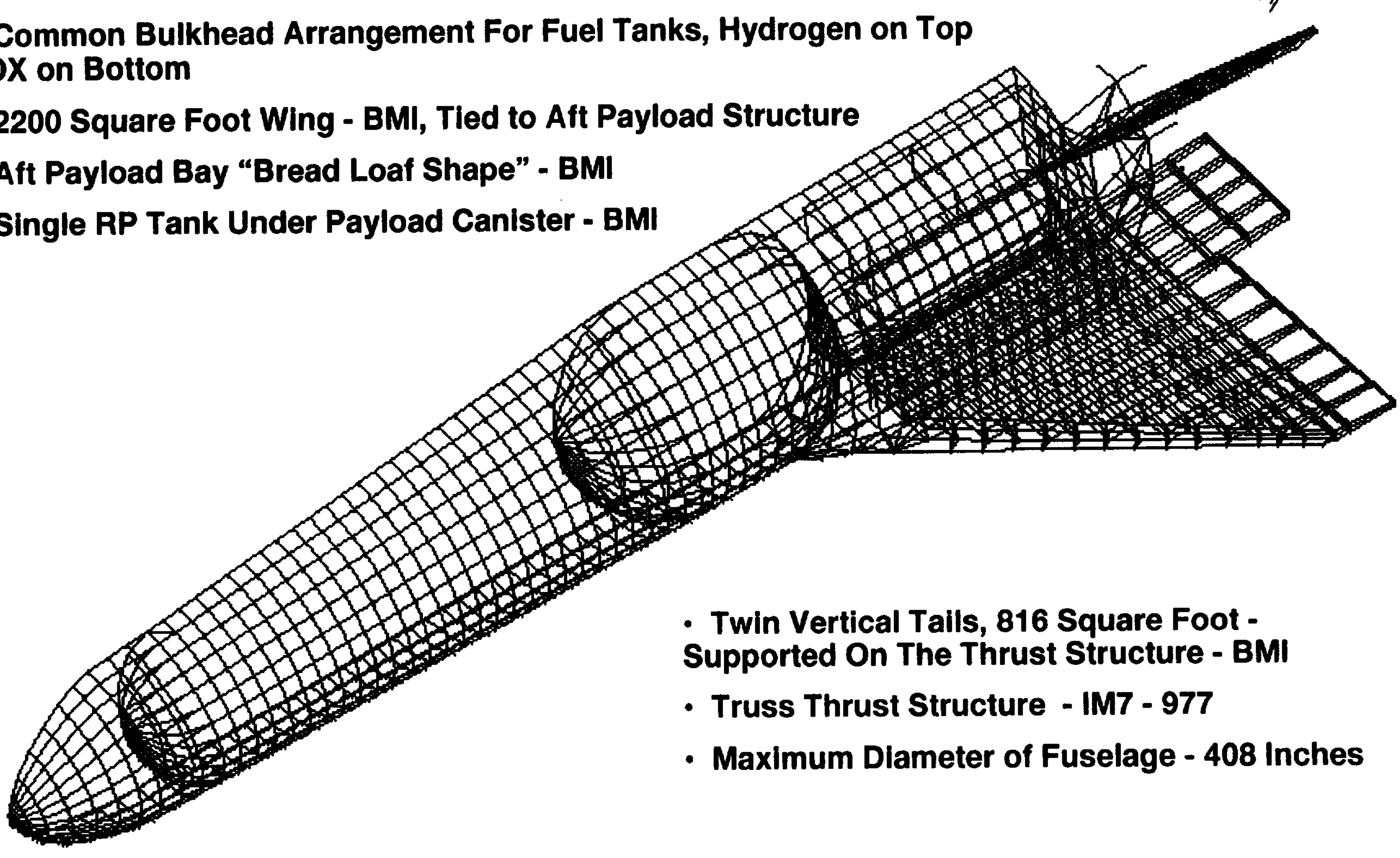
- 2200 Square Foot Wing - BMI, Tied with Struts to LOX Tank
- Twin Vertical Tails, 816 Square Foot - Supported On The Thrust Structure - BMI
- Conical Thrust Structure - IM7 - 977
- Maximum Diameter of Fuselage - 384 Inches

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Configuration 4A - 1 Finite Element Model

SSTO

- Common Bulkhead Arrangement For Fuel Tanks, Hydrogen on Top LOX on Bottom
- 2200 Square Foot Wing - BMI, Tied to Aft Payload Structure
- Aft Payload Bay "Bread Loaf Shape" - BMI
- Single RP Tank Under Payload Canister - BMI



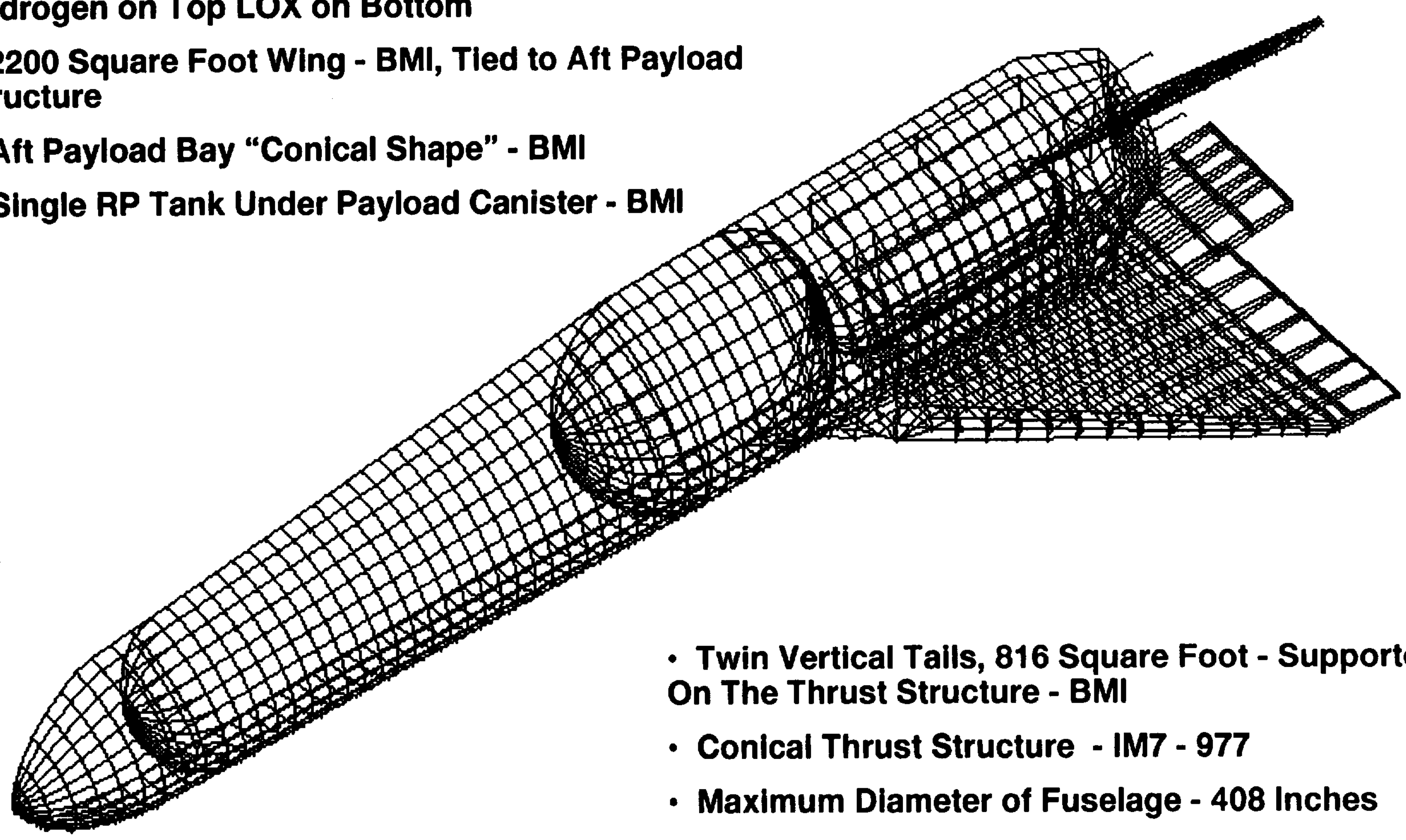
- Twin Vertical Tails, 816 Square Foot - Supported On The Thrust Structure - BMI
- Truss Thrust Structure - IM7 - 977
- Maximum Diameter of Fuselage - 408 Inches

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Configuration 4A -2 Finite Element Model

SSTO

- Common Bulkhead Arrangement For Fuel Tanks, Hydrogen on Top LOX on Bottom
- 2200 Square Foot Wing - BMI, Tied to Aft Payload Structure
- Aft Payload Bay "Conical Shape" - BMI
- Single RP Tank Under Payload Canister - BMI

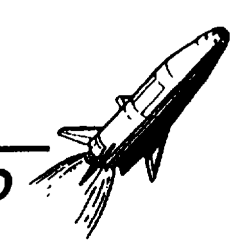


- Twin Vertical Tails, 816 Square Foot - Supported On The Thrust Structure - BMI
- Conical Thrust Structure - IM7 - 977
- Maximum Diameter of Fuselage - 408 Inches

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Load Factors For Finite Element Model Configuration 1A

SSTO

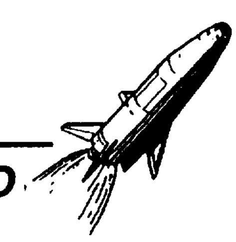


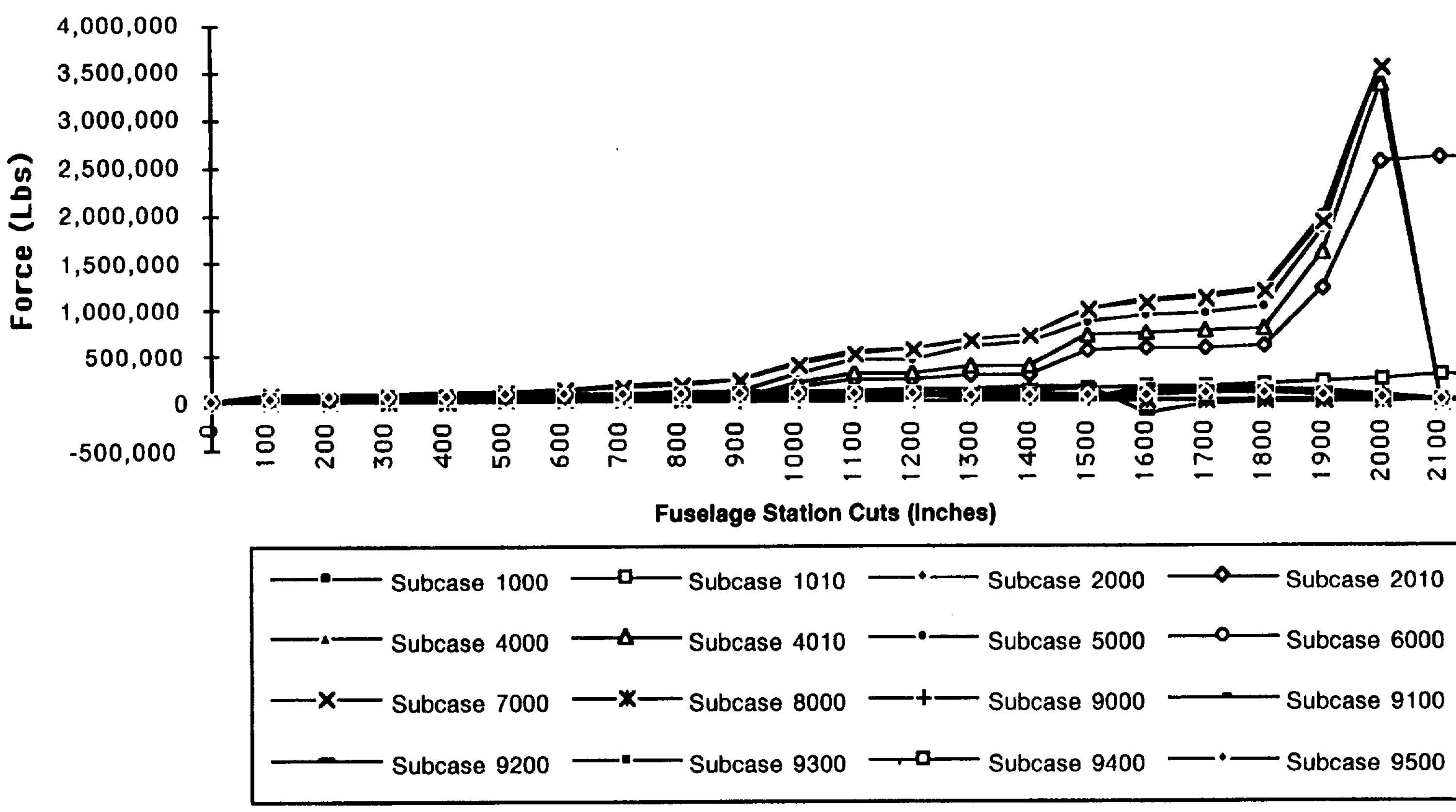
LOAD CASE DESCRIPTION	FUEL TANK WEIGHTS			Payload	LOAD FACTORS (ACCELERATIONS)			ENGINE THRUST
	LH2 TANK Lbs	LOX TANK Lbs	RP TANK Lbs	Weight Lbs	Nx g's	Ny g's	Nz g's	Lbs
Prelaunch - Unfueled - wind - Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Unfueled - wind +Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind - Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind +Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Lift-off - wind - Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	-0.0460	3,394,288
Lift-off - wind +Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	-0.0139	3,394,288
Max q Alpha - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	-0.2206	3,775,080
Max q Alpha - negative angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	0.4846	3,778,352
Max q Beta - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	TBD	0.0000	TBD
Max Thrust - angle of attack is zero	99,850	766,184	46,373	40,000	3.1500	0.0000	-0.0534	3,711,072
TAEM Maneuver 2.5 g	917	9,502	1,110	40,000	-0.5877	0.0000	2.5000	0
Main Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.8089	0.0000	3.2917	0
Main Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.9363	0.0000	2.7078	0
Main Gear Landing - Springback	917	9,502	1,110	40,000	0.3140	0.0000	3.0690	0
Nose Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.5047	0.0000	2.0920	0
Nose Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.5681	0.0000	2.8884	0
Nose Gear Landing - Springback	917	9,502	1,110	40,000	-0.5309	0.0000	2.8276	0

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Configuration 1A - Axial Force

SSTO

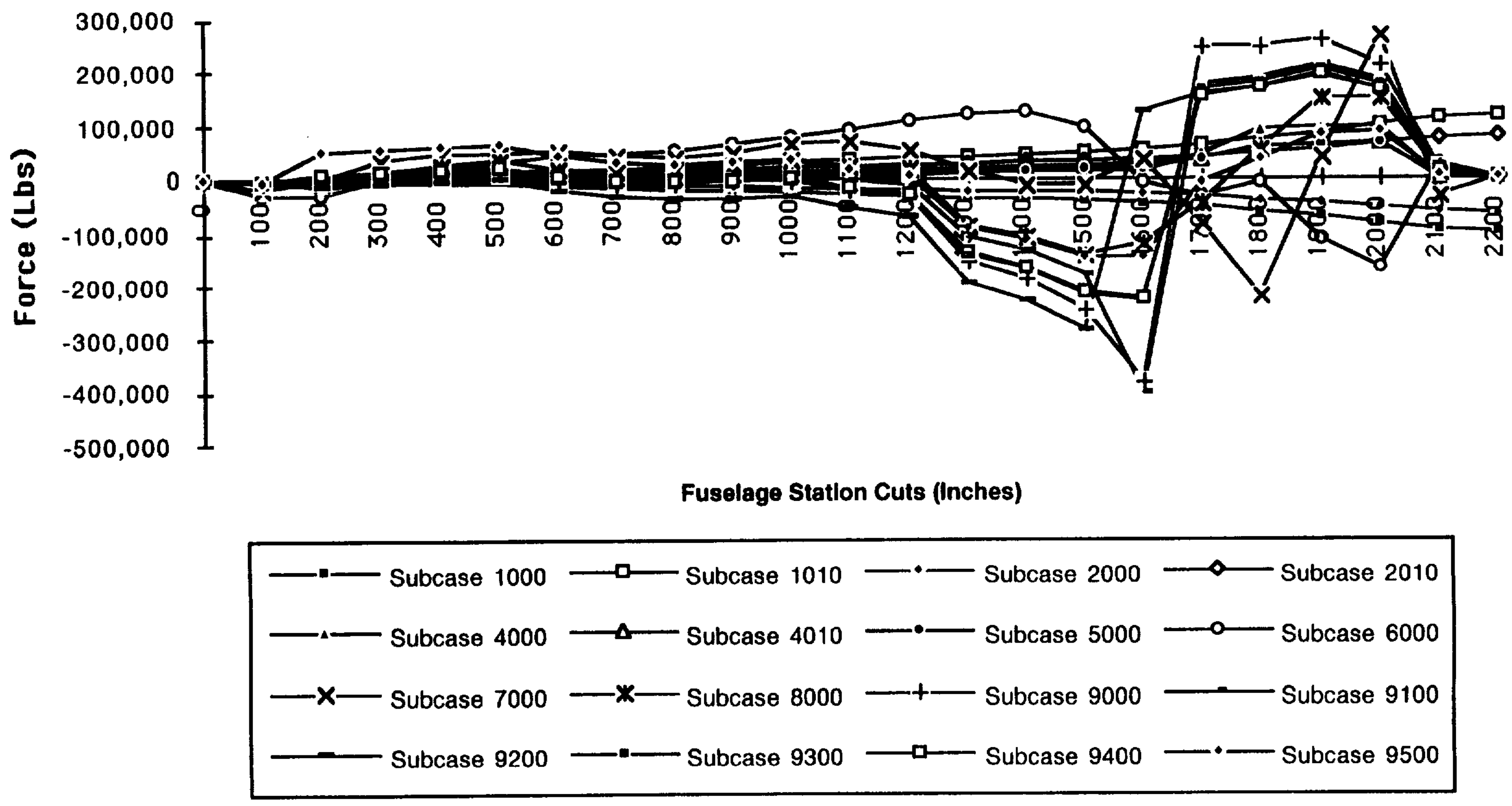




NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

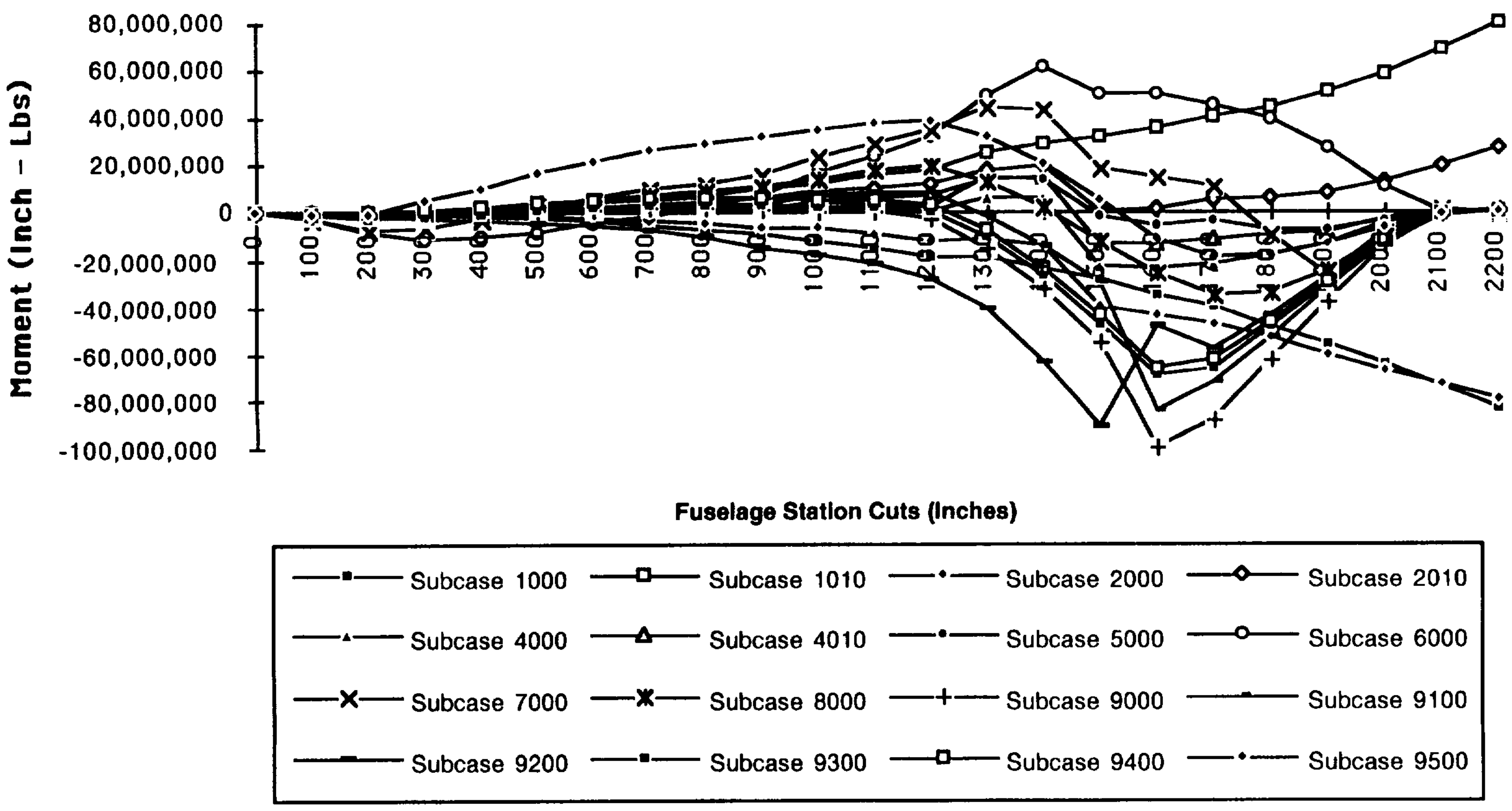
Configuration 1A - Shear Force

SSTO

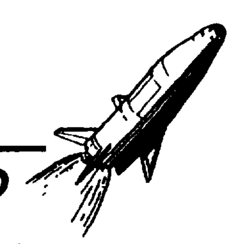


Configuration 1A - Pitching Moment

SSTO



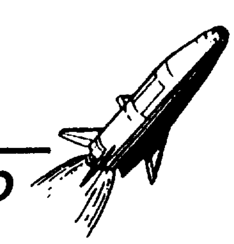
Load Factors For Finite Element Model Configuration 1B

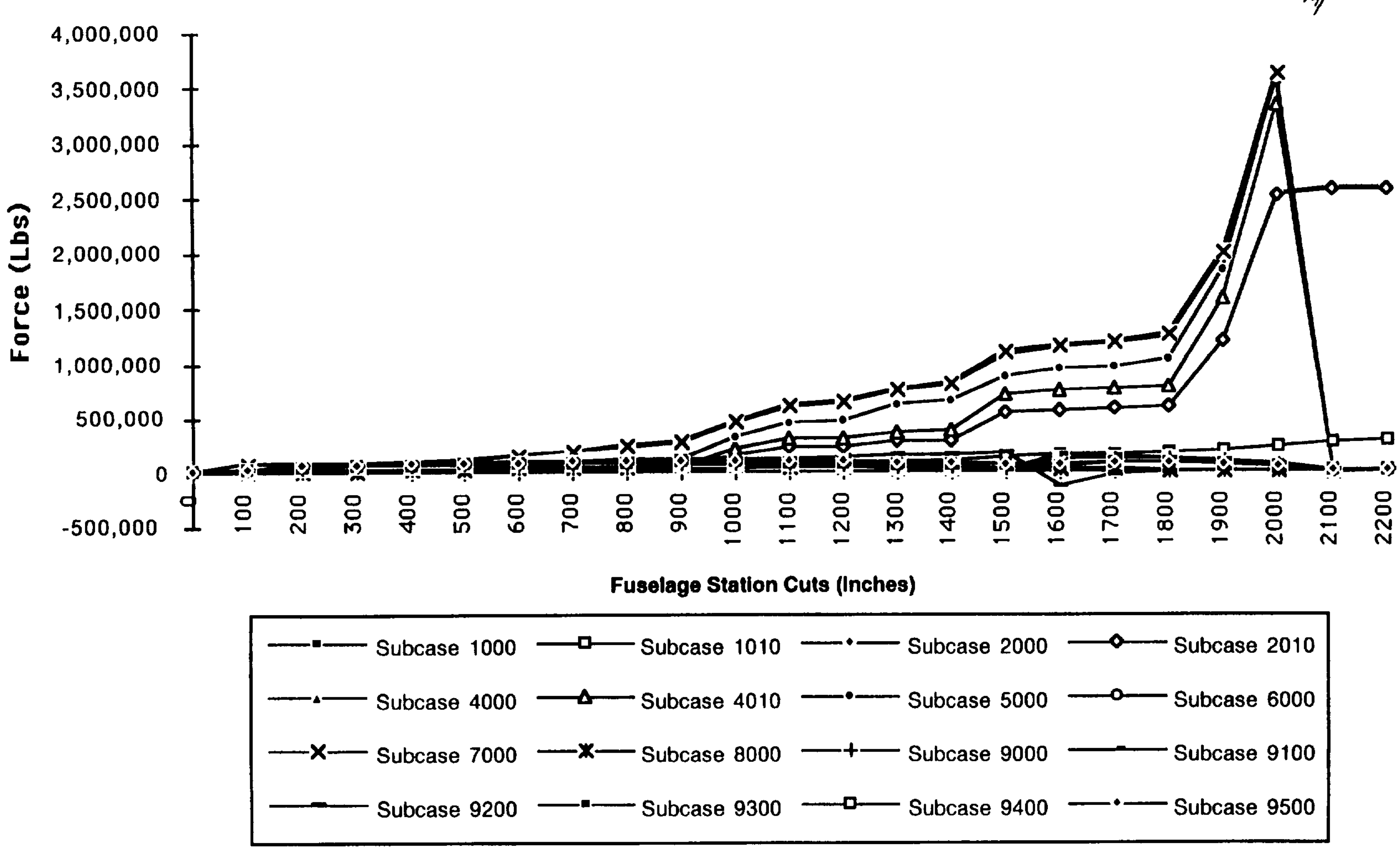


SSTO

LOAD CASE DESCRIPTION	FUEL TANK WEIGHTS			Payload Weight Lbs	LOAD FACTORS (ACCELERATIONS)			ENGINE THRUST Lbs
	LH2 TANK Lbs	LOX TANK Lbs	RP TANK Lbs		Nx g's	Ny g's	Nz g's	
Prelaunch - Unfueled - wind - Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Unfueled - wind +Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind - Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind +Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Lift-off - wind - Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	-0.0464	3,401,816
Lift-off - wind +Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	-0.0134	3,401,816
Max q Alpha - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	0.4690	3,860,032
Max q Alpha - negative angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	-0.1190	3,781,024
Max q Beta - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	TBD	0.0000	TBD
Max Thrust - angle of attack is zero	99,850	766,184	46,373	40,000	3.1500	0.0000	-0.0523	3,729,040
TAEM Maneuver 2.5 g	917	9,502	1,110	40,000	-0.5609	0.0000	2.5000	0
Main Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.8258	0.0000	2.8187	0
Main Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.9048	0.0000	2.4247	0
Main Gear Landing - Springback	917	9,502	1,110	40,000	0.3271	0.0000	2.7476	0
Nose Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.5043	0.0000	1.8672	0
Nose Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.5700	0.0000	2.7007	0
Nose Gear Landing - Springback	917	9,502	1,110	40,000	-0.5339	0.0000	2.6725	0

Configuration 1B - Axial Force

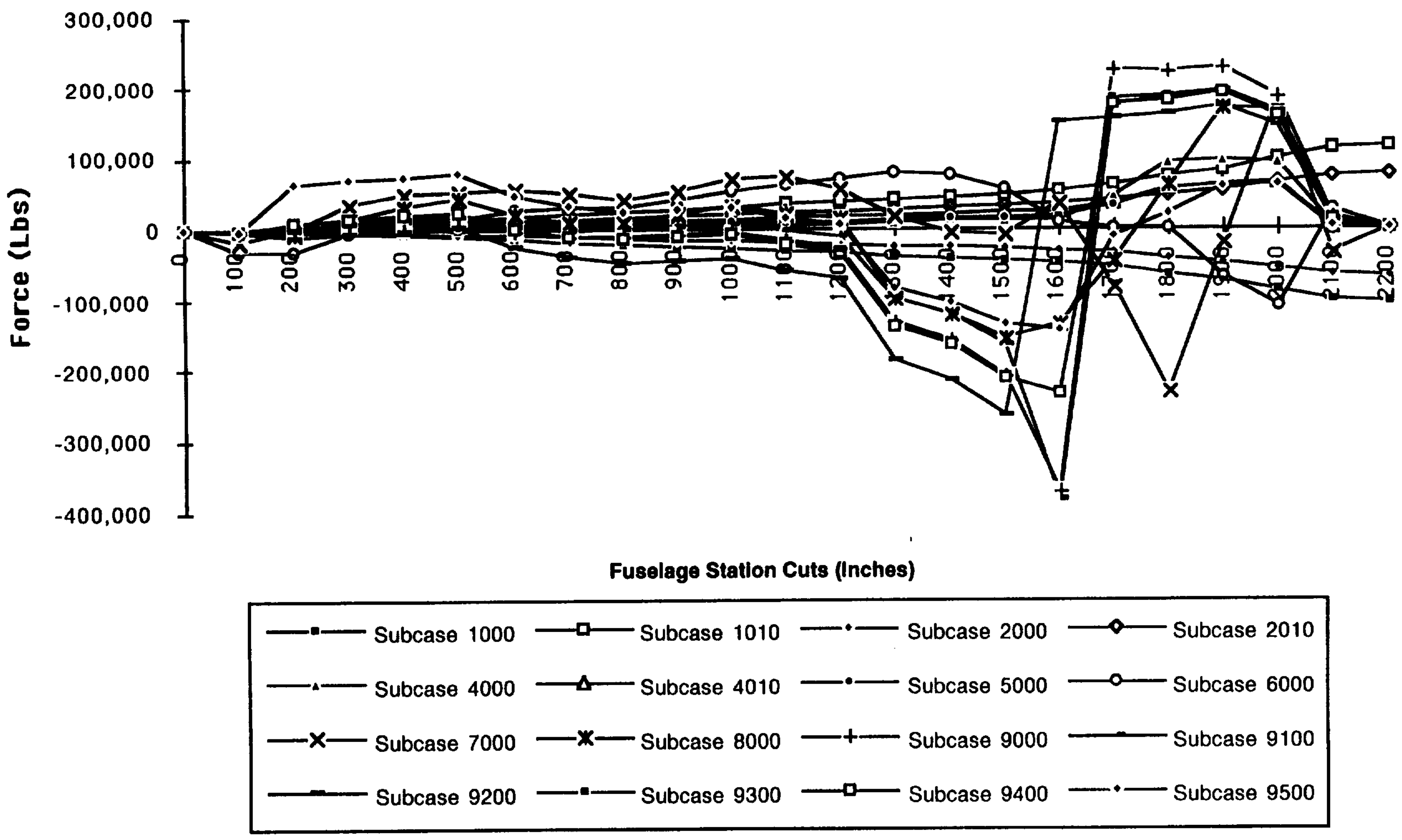




NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Configuration 1B - Shear Force

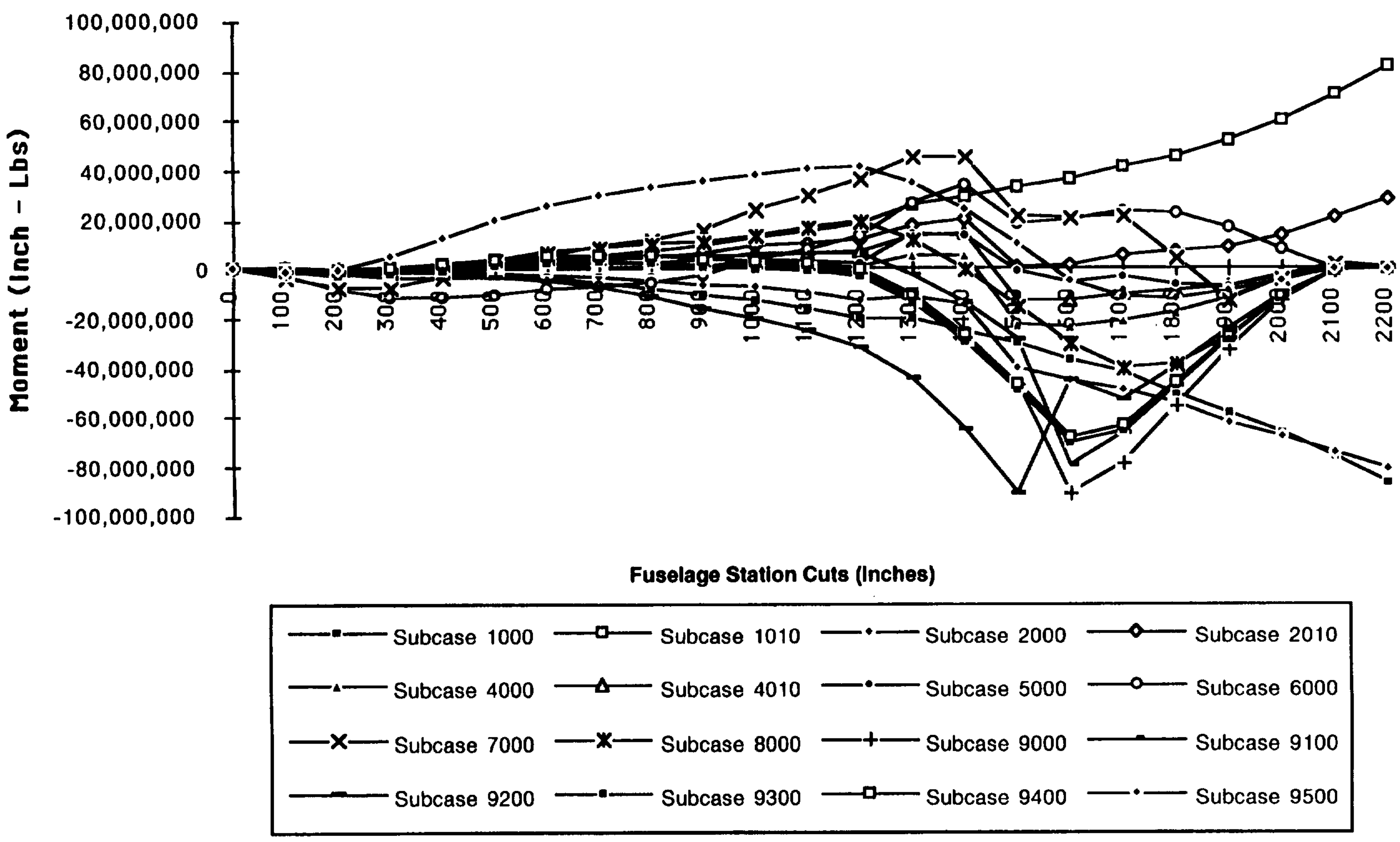
SSTO



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Configuration 1B - Pitching Moment

SSTO



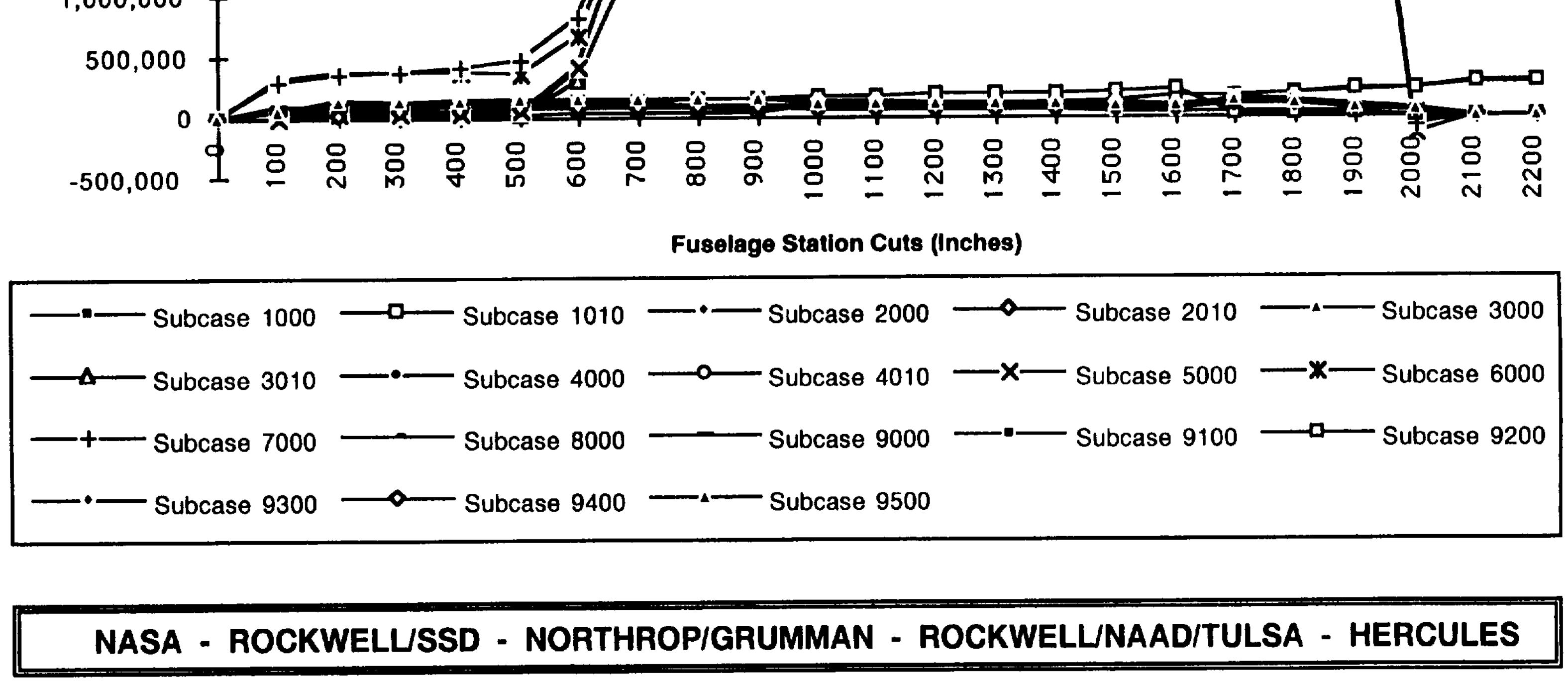
Load Factors For Finite Element Model Configuration 2A

SSTO

LOAD CASE DESCRIPTION	FUEL TANK WEIGHTS			Payload	LOAD FACTORS (ACCELERATIONS)			ENGINE
	LH2 TANK Lbs	LOX TANK Lbs	RP TANK Lbs	Weight Lbs	Nx g's	Ny g's	Nz g's	THRUST Lbs
Prelaunch - Unfueled - wind - Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Unfueled - wind +Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind - Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind +Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Lift-off - wind - Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	-0.0123	3,393,584
Lift-off - wind +Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	0.0027	3,394,888
Max q Alpha - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	0.5294	4,009,344
Max q Alpha - negative angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	-0.2879	3,960,368
Max q Beta - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	TBD	0.0000	TBD
Max Thrust - angle of attack is zero	99,850	766,184	46,373	40,000	3.1500	0.0000	-0.0066	3,704,368
TAEM Maneuver 2.5 g	917	9,502	1,110	40,000	-0.6494	0.0000	2.5000	0
Main Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.6432	0.0000	3.7748	0
Main Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.8645	0.0000	1.8337	0
Main Gear Landing - Springback	917	9,502	1,110	40,000	0.3703	0.0000	2.0095	0
Nose Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.7941	0.0000	3.3739	0
Nose Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.7812	0.0000	3.0547	0
Nose Gear Landing - Springback	917	9,502	1,110	40,000	-0.4805	0.0000	3.1659	0

Configuration 2A - Axial Force

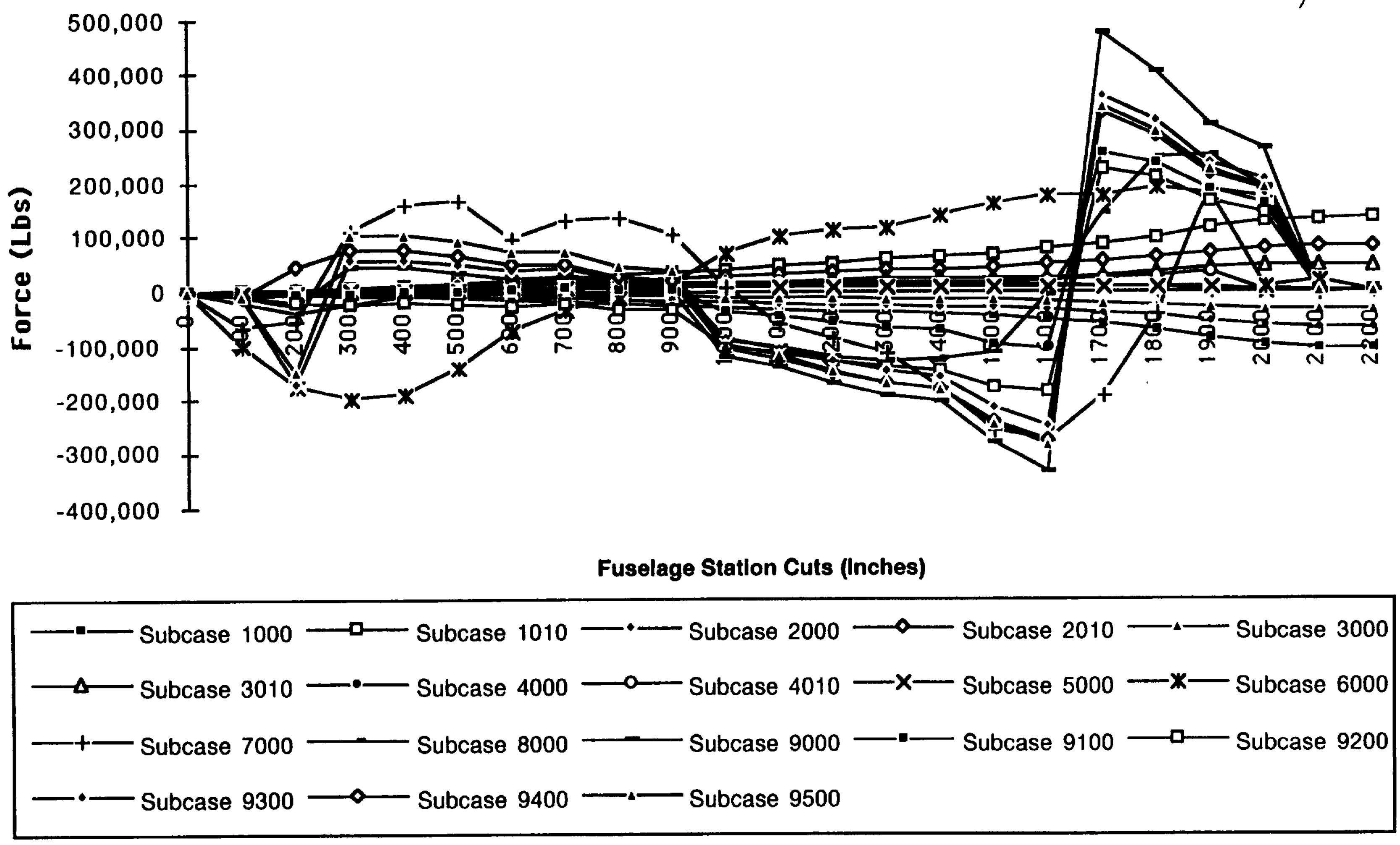
SSTO



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Configuration 2A - Shear Force

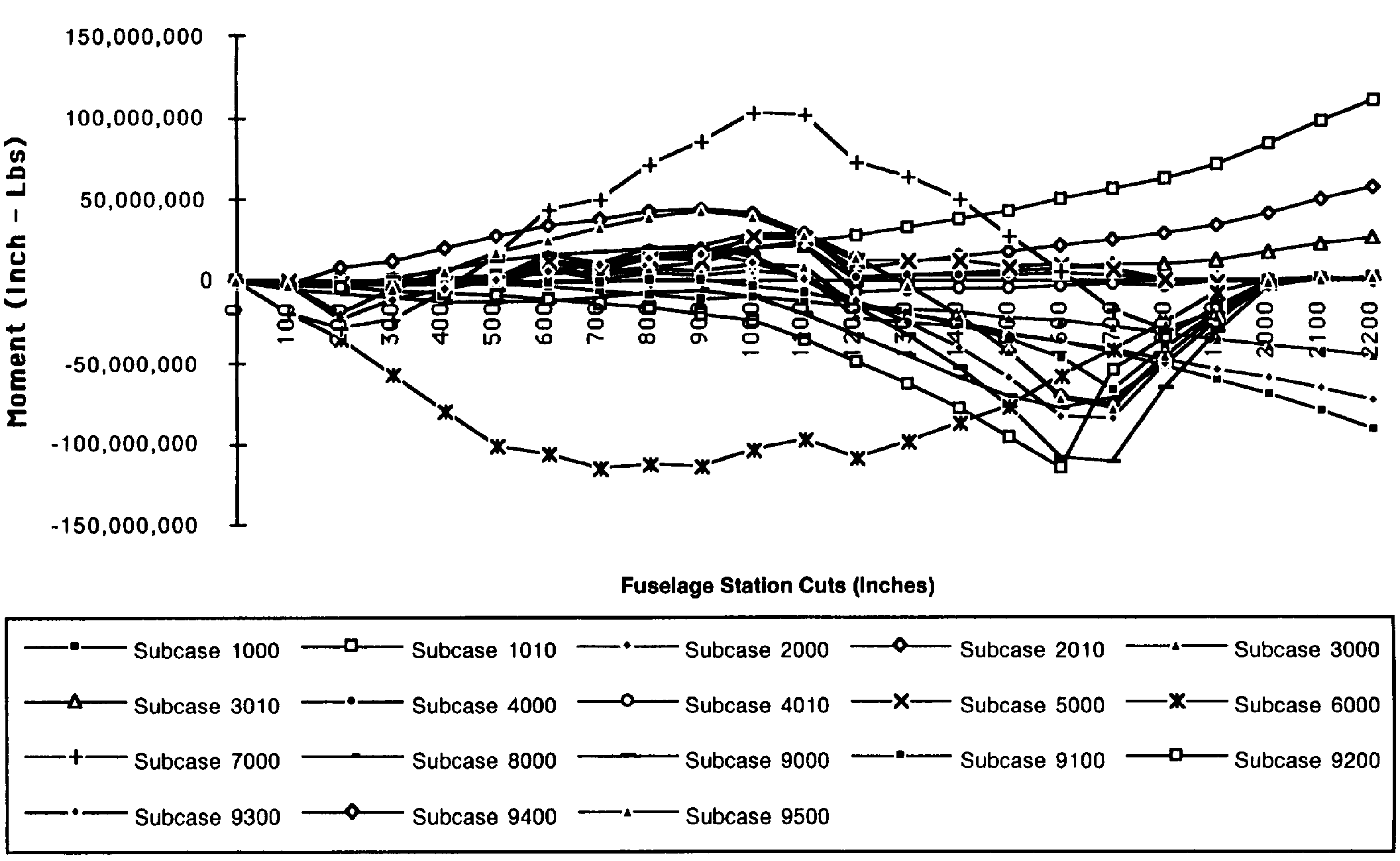
SSTO



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Configuration 2A - Pitching Moment

SSTO



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Load Factors For Finite Element Model Configuration 2B

SSTO

LOAD CASE DESCRIPTION	FUEL TANK WEIGHTS LH2 TANK Lbs	FUEL TANK WEIGHTS LOX TANK Lbs	FUEL TANK WEIGHTS RP TANK Lbs	Payload Weight Lbs	LOAD FACTORS (ACCELERATIONS) Nx g's	LOAD FACTORS (ACCELERATIONS) Ny g's	LOAD FACTORS (ACCELERATIONS) Nz g's	ENGINE THRUST Lbs
Prelaunch - Unfueled - wind - Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Unfueled - wind +Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind - Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind +Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Lift-off - wind - Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	-0.0109	3,394,000
Lift-off - wind +Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	0.0016	3,395,088
Max q Alpha - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	0.5098	4,065,008
Max q Alpha - negative angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	-0.3546	4,063,648
Max q Beta - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	TBD	0.0000	TBD
Max Thrust - angle of attack is zero	99,850	766,184	46,373	40,000	3.1500	0.0000	-0.0056	3,704,368
TAEM Maneuver 2.5 g	917	9,502	1,110	40,000	-0.7995	0.0000	2.5000	0
Main Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.6885	0.0000	3.0935	0
Main Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.9754	0.0000	2.0224	0
Main Gear Landing - Springback	917	9,502	1,110	40,000	0.2271	0.0000	1.6765	0
Nose Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.8918	0.0000	3.2518	0
Nose Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.8675	0.0000	2.8053	0
Nose Gear Landing - Springback	917	9,502	1,110	40,000	-0.5485	0.0000	2.9780	0

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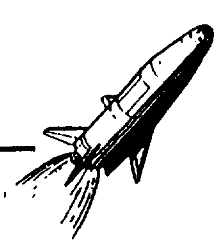
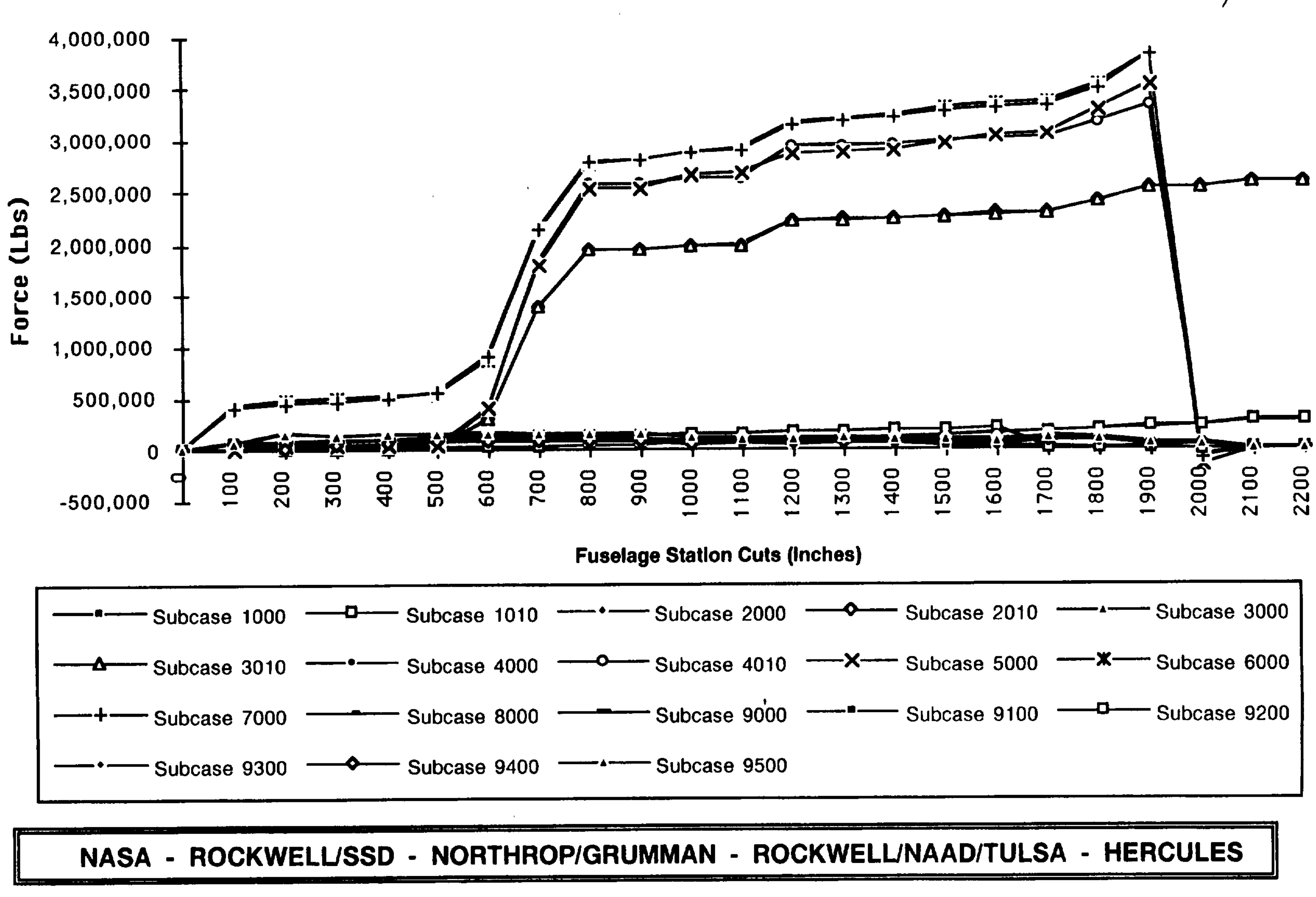
Configuration 2B - Axial Force

SSTO





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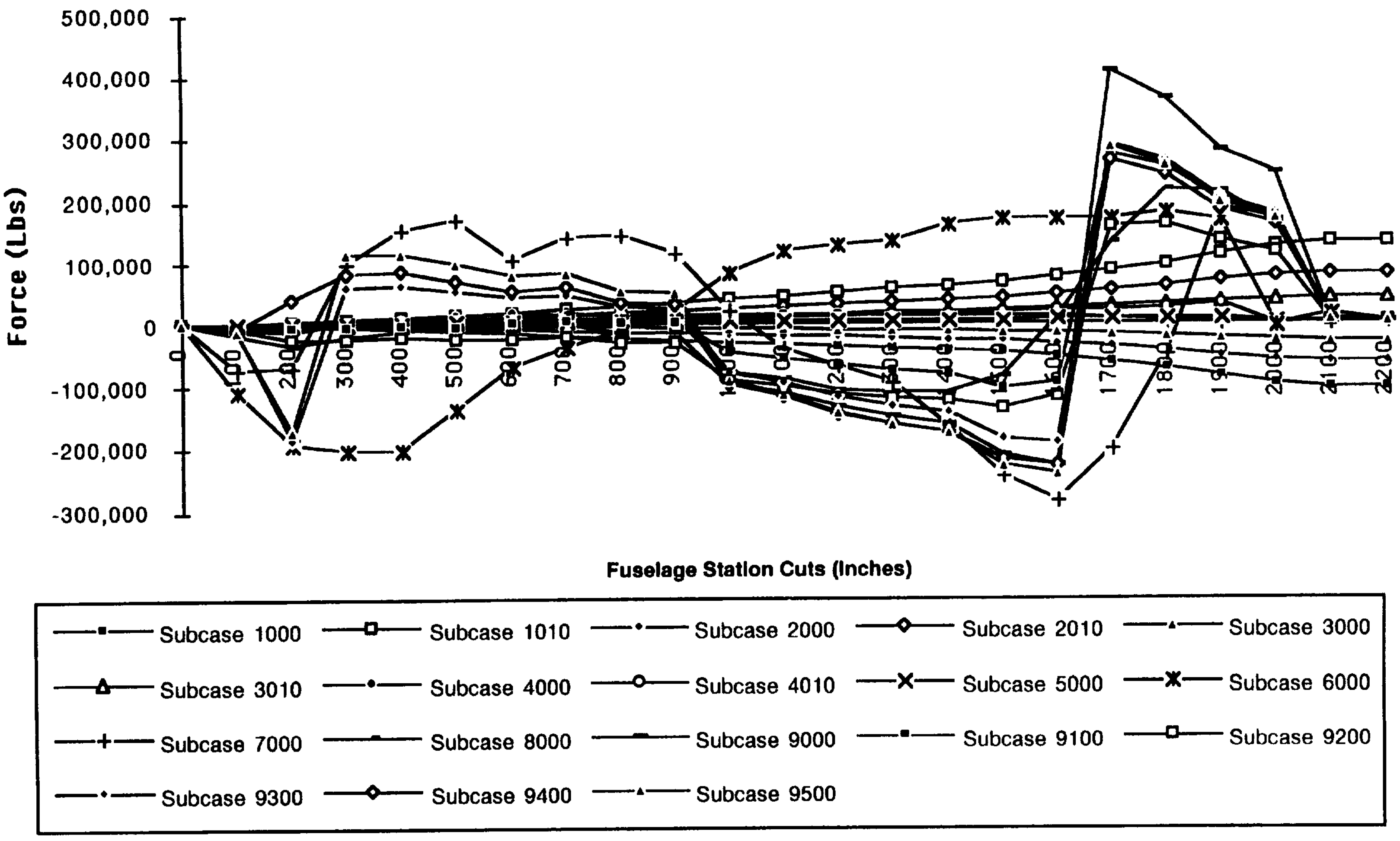
Configuration 2B - Shear Force

SSTO



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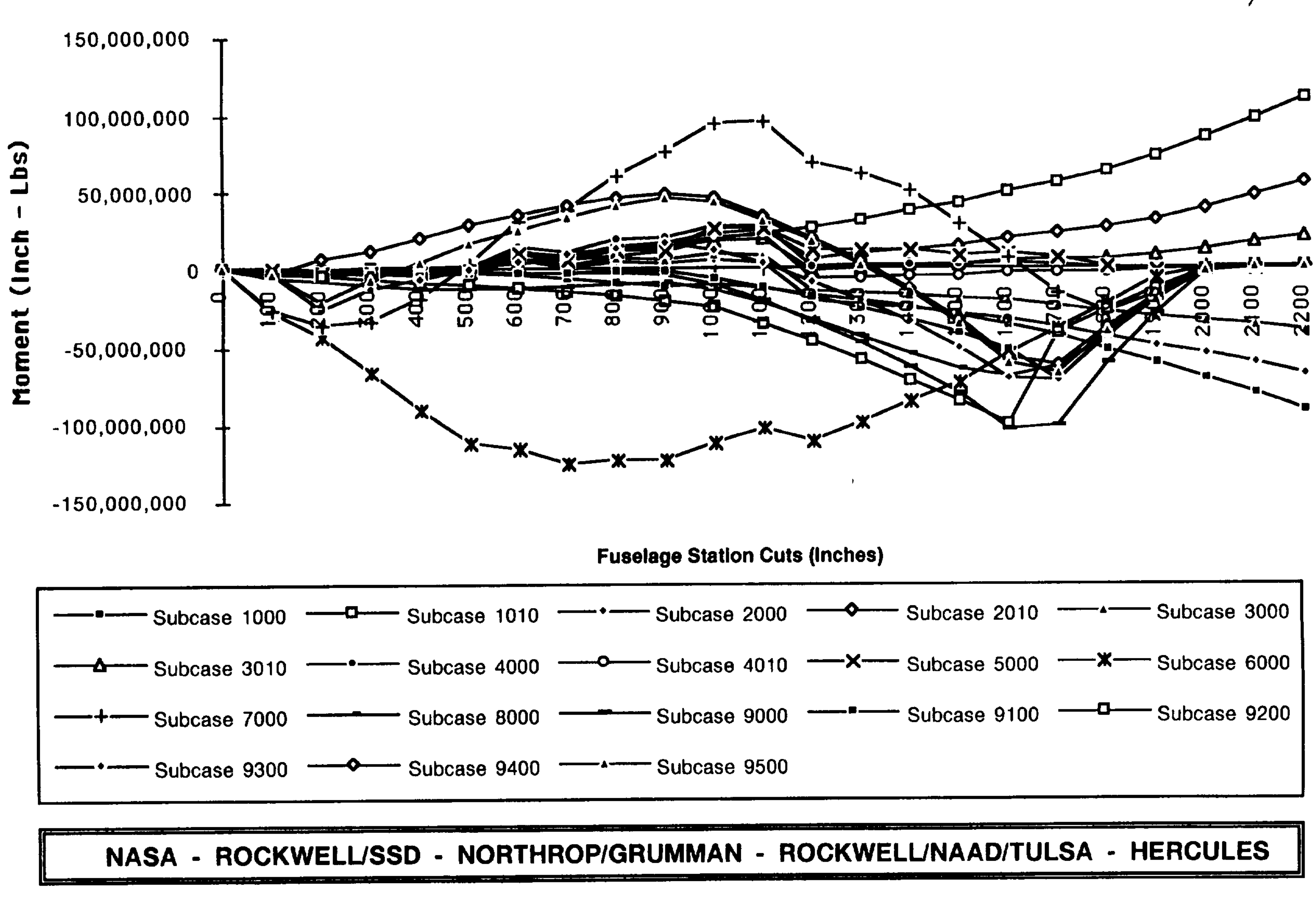
Configuration 2B - Pitching Moment

SSTO



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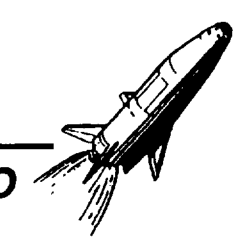
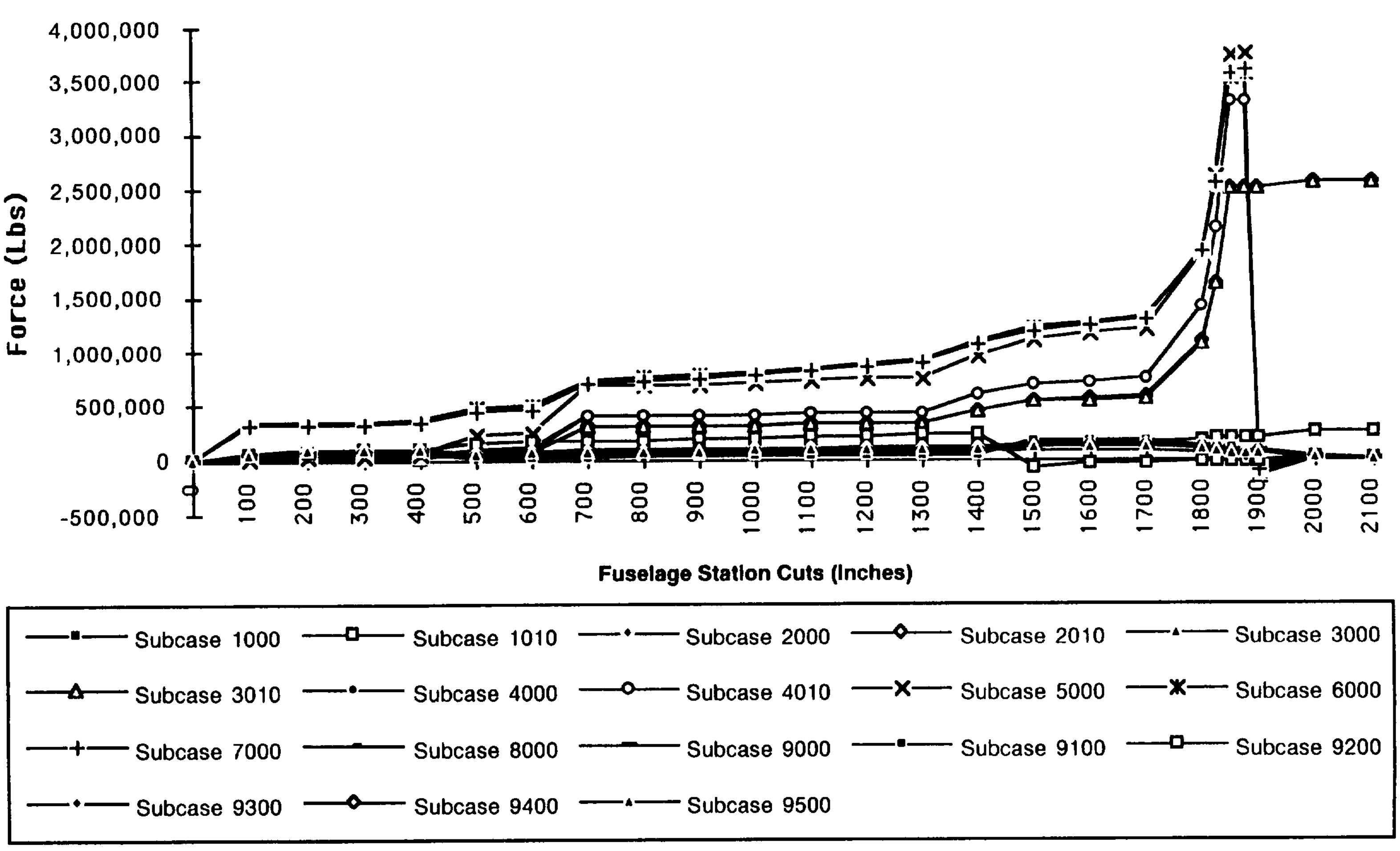
Load Factors For Finite Element Model Configuration 3

LOAD CASE DESCRIPTION	FUEL TANK WEIGHTS			Payload	LOAD FACTORS (ACCELERATIONS)			ENGINE THRUST
	LH2 TANK Lbs	LOX TANK Lbs	RP TANK Lbs	Weight Lbs	Nx g's	Ny g's	Nz g's	Lbs
Prelaunch - Unfueled - wind - Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Unfueled - wind +Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind - Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind +Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Lift-off - wind - Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	-0.0307	3,352,592
Lift-off - wind +Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	0.0054	3,352,712
Max q Alpha - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	0.3299	3,788,432
Max q Alpha - negative angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	-0.5567	3,747,064
Max q Beta - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	TBD	0.0000	TBD
Max Thrust - angle of attack is zero	99,850	766,184	46,373	40,000	3.1500	0.0000	-0.0747	3,898,368
TAEM Maneuver 2.5 g	917	9,502	1,110	40,000	-0.6830	0.0000	2.5000	0
Main Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.9619	0.0000	3.1066	0
Main Gear Landing - Spin-up	917	9,502	1,110	40,000	-1.1100	0.0000	2.4904	0
Main Gear Landing - Springback	917	9,502	1,110	40,000	0.7478	0.0000	2.8680	0
Nose Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.6660	0.0000	2.2954	0
Nose Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.7176	0.0000	2.9968	0
Nose Gear Landing - Springback	917	9,502	1,110	40,000	-0.6483	0.0000	2.9993	0

Configuration 3 - Axial Force



SSTO



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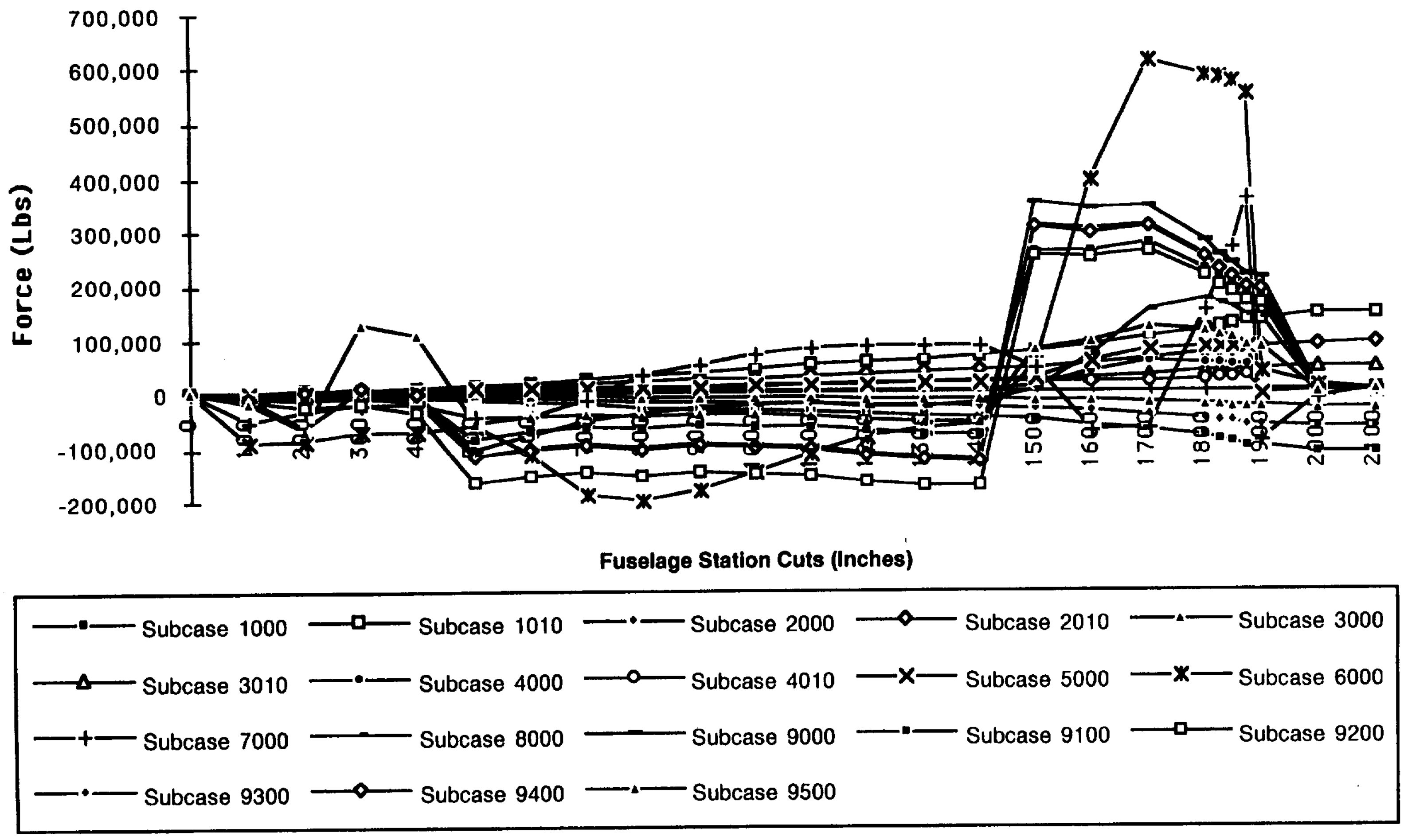
Configuration 3 - Shear Force

SSTO



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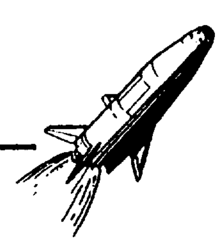
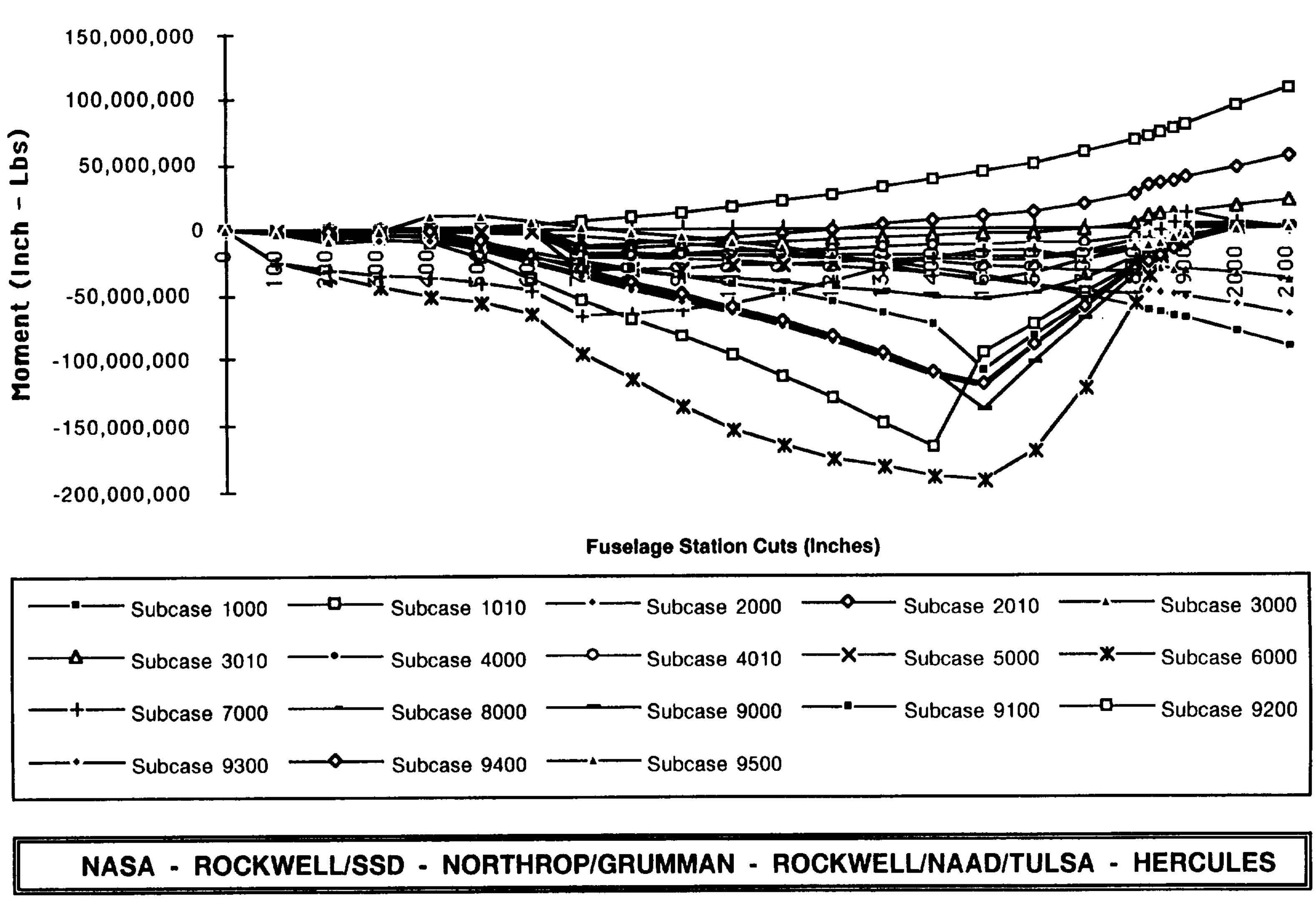
Configuration 3 - Pitching Moment



SSTO



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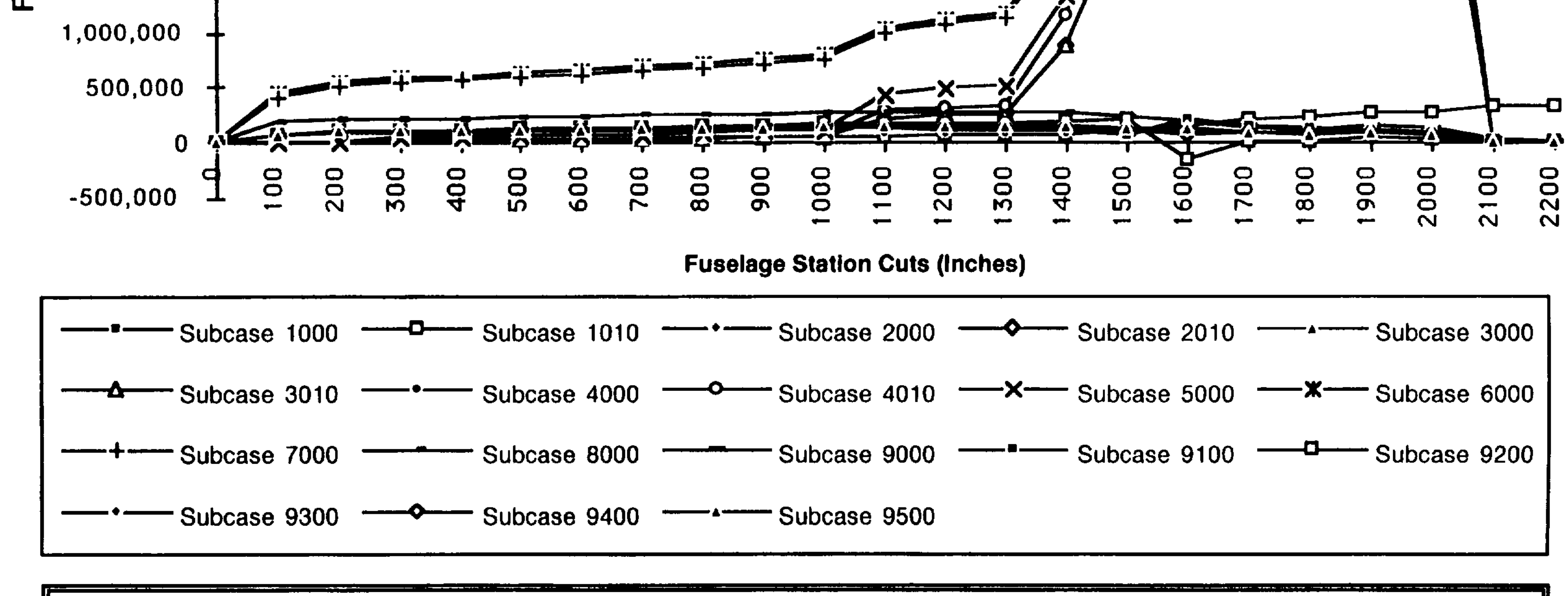
Load Factors For Finite Element Model Configuration 4A - 1

SSTO

LOAD CASE DESCRIPTION	FUEL TANK WEIGHTS LH2 TANK Lbs	FUEL TANK WEIGHTS LOX TANK Lbs	FUEL TANK WEIGHTS RP TANK Lbs	Payload Weight Lbs	LOAD FACTORS (ACCELERATIONS) Nx g's	LOAD FACTORS (ACCELERATIONS) Ny g's	LOAD FACTORS (ACCELERATIONS) Nz g's	ENGINE THRUST Lbs
Prelaunch - Unfueled - wind - Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Unfueled - wind +Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind - Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind +Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Lift-off - wind - Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	-0.0212	3,480,234
Lift-off - wind +Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	-0.0003	3,480,234
Max q Alpha - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	0.0770	4,410,134
Max q Alpha - negative angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	0.0770	4,317,210
Max q Beta - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	TBD	0.0000	TBD
Max Thrust - angle of attack is zero	99,850	766,184	46,373	40,000	3.1500	0.0000	-0.0135	3,915,768
TAEM Maneuver 2.5 g	917	9,502	1,110	40,000	-1.2306	0.0000	2.5000	0
Main Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.8647	0.0000	1.6110	0
Main Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.9239	0.0000	1.2963	0
Main Gear Landing - Springback	917	9,502	1,110	40,000	0.1480	0.0000	1.8973	0
Nose Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.4856	0.0000	1.2367	0
Nose Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.5525	0.0000	1.5800	0
Nose Gear Landing - Springback	917	9,502	1,110	40,000	-0.5248	0.0000	1.5644	0

Configuration 4A - Axial Force

SSTO



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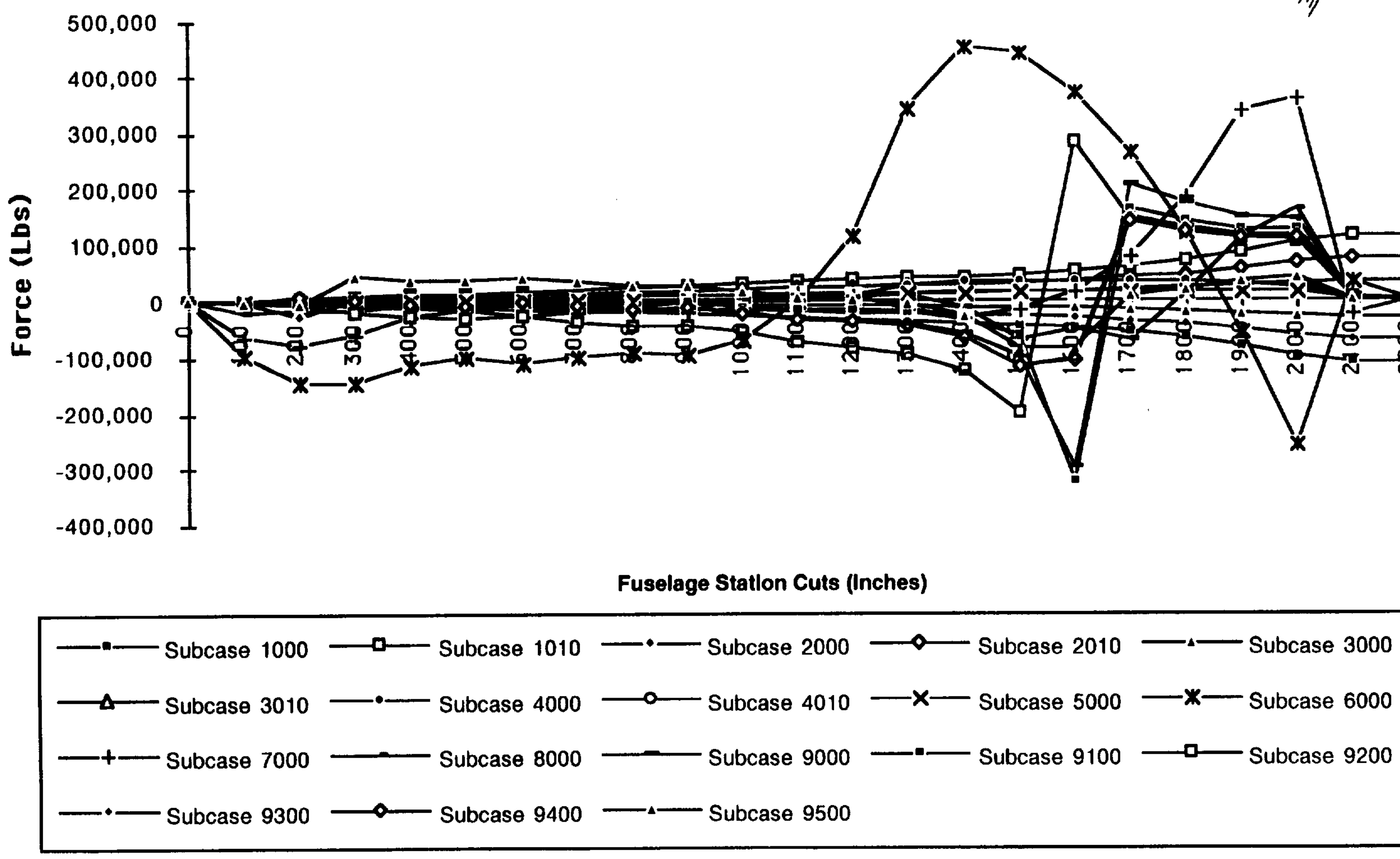
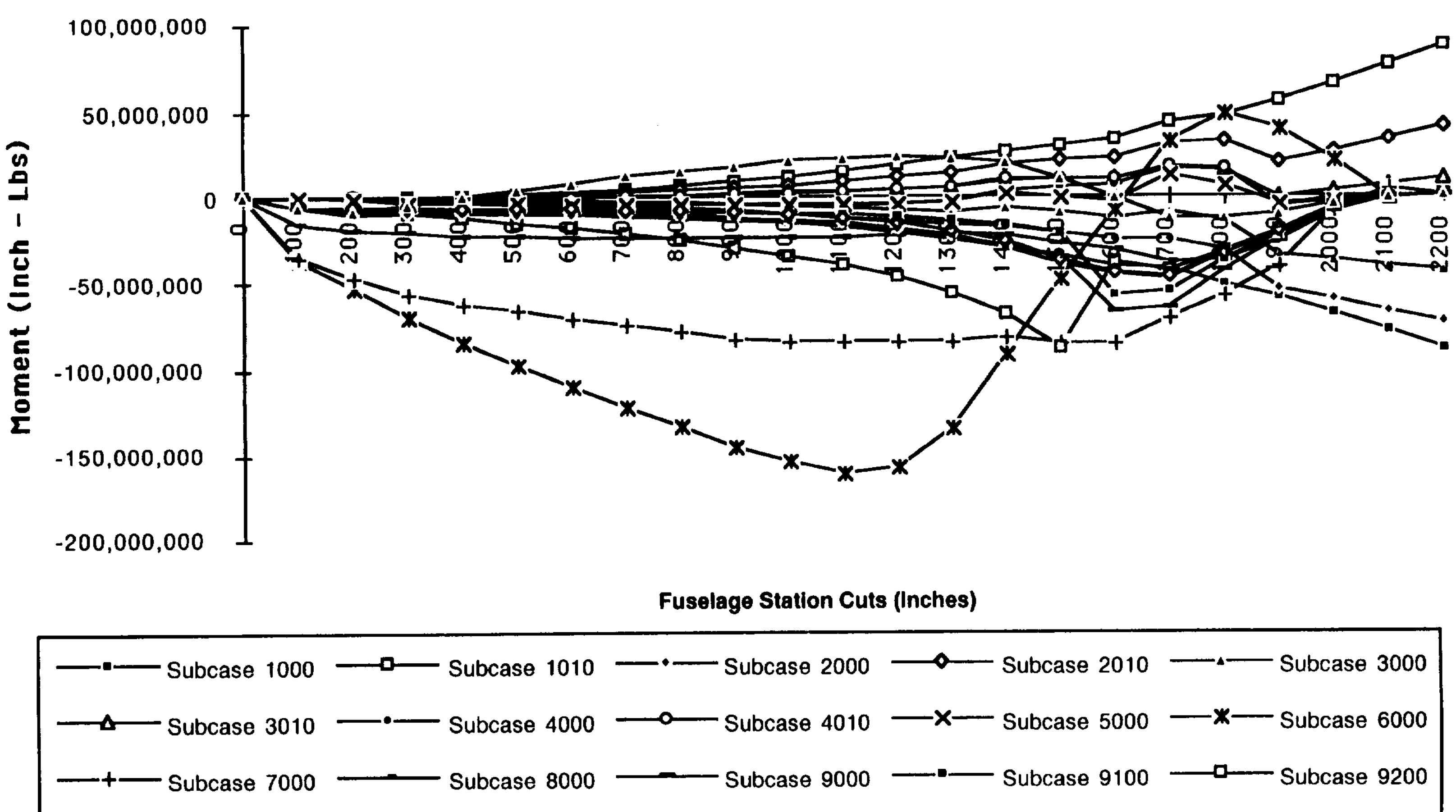
Configuration 4A - Shear Force

SSTO



Configuration 4A - Pitching Moment

SSTO



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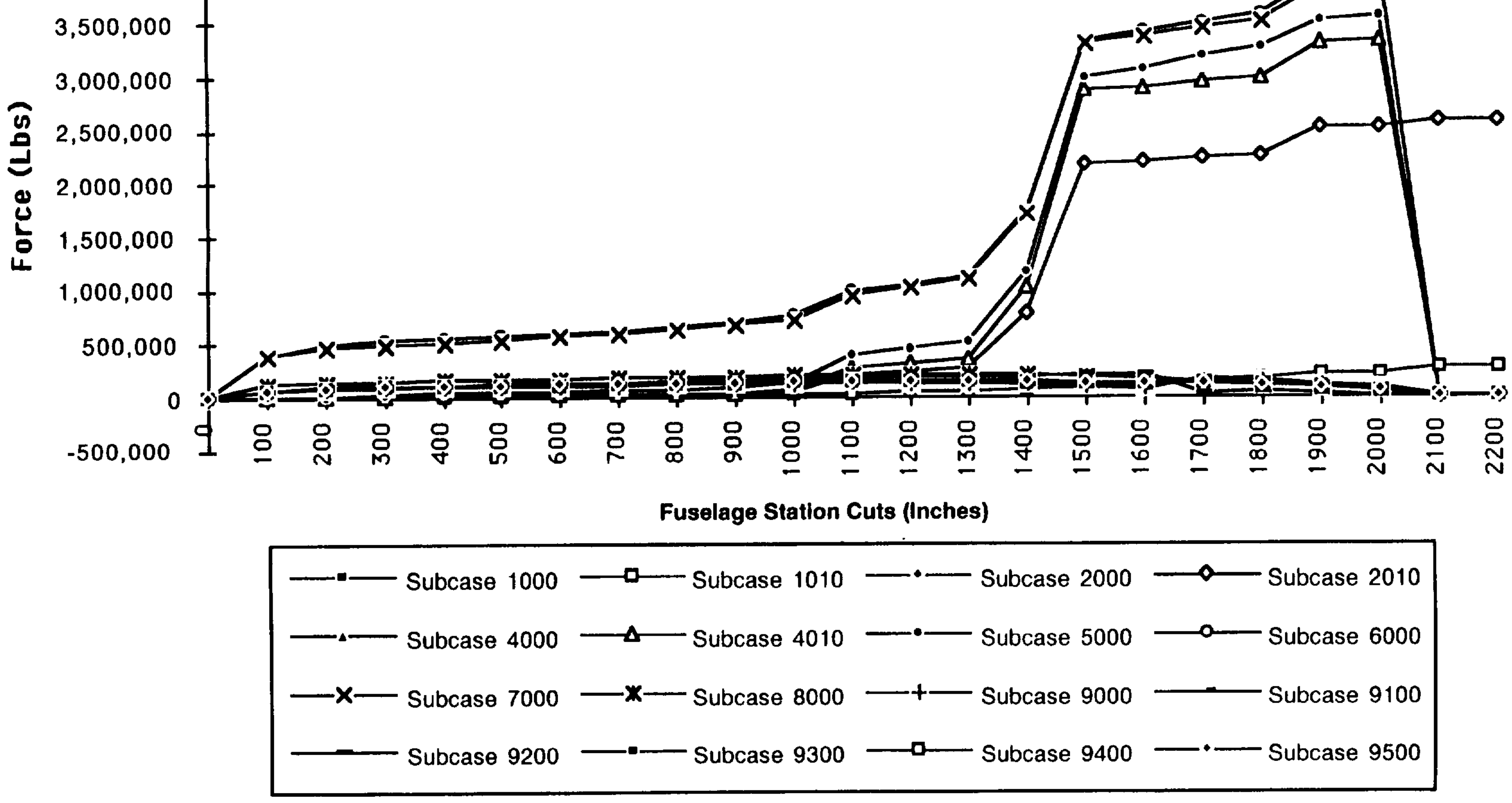
Load Factors For Finite Element Model Configuration 4A - 2

SSTO

LOAD CASE DESCRIPTION	FUEL TANK WEIGHTS LH2 TANK Lbs	LOX TANK Lbs	RP TANK Lbs	Payload Weight Lbs	LOAD FACTORS (ACCELERATIONS) Nx g's	Ny g's	Nz g's	ENGINE THRUST Lbs
Prelaunch - Unfueled - wind - Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Unfueled - wind +Z direction	0	0	0	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind - Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Prelaunch - Fueled - wind +Z direction	183,456	1,900,444	221,946	40,000	1.0000	0.0000	0.0000	0
Lift-off - wind - Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	-0.0234	3,394,856
Lift-off - wind +Z direction	183,456	1,900,444	221,946	40,000	1.3200	0.0000	-0.0029	3,394,856
Max q Alpha - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	0.0917	4,172,648
Max q Alpha - negative angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	0.0000	-0.3643	4,216,696
Max q Beta - positive angle of attack (4 Degrees)	143,743	1,361,670	138,549	40,000	1.5500	TBD	0.0000	TBD
Max Thrust - angle of attack is zero	99,850	766,184	46,373	40,000	3.1500	0.0000	-0.0230	3,712,096
TAEM Maneuver 2.5 g	917	9,502	1,110	40,000	-0.8954	0.0000	2.5000	0
Main Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.7379	0.0000	2.5066	0
Main Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.8837	0.0000	1.9205	0
Main Gear Landing - Springback	917	9,502	1,110	40,000	0.3784	0.0000	2.2841	0
Nose Gear Landing - Max Vertical Load	917	9,502	1,110	40,000	-0.4343	0.0000	1.2504	0
Nose Gear Landing - Spin-up	917	9,502	1,110	40,000	-0.4571	0.0000	2.0664	0
Nose Gear Landing - Springback	917	9,502	1,110	40,000	-0.4258	0.0000	2.0284	0

Configuration 4B - Axial Force

SSTO



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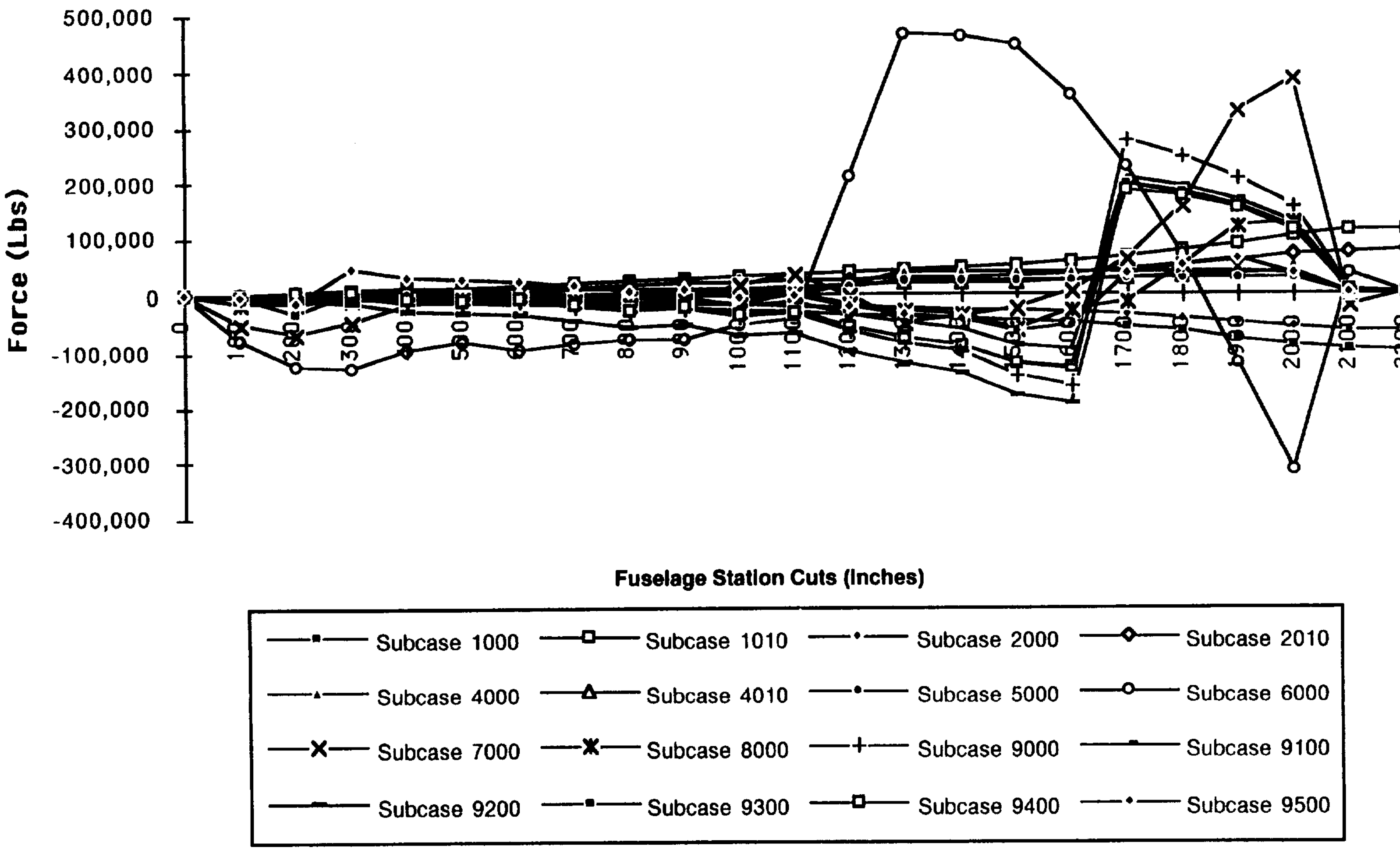
Configuration 4B - Shear Force

SSTO



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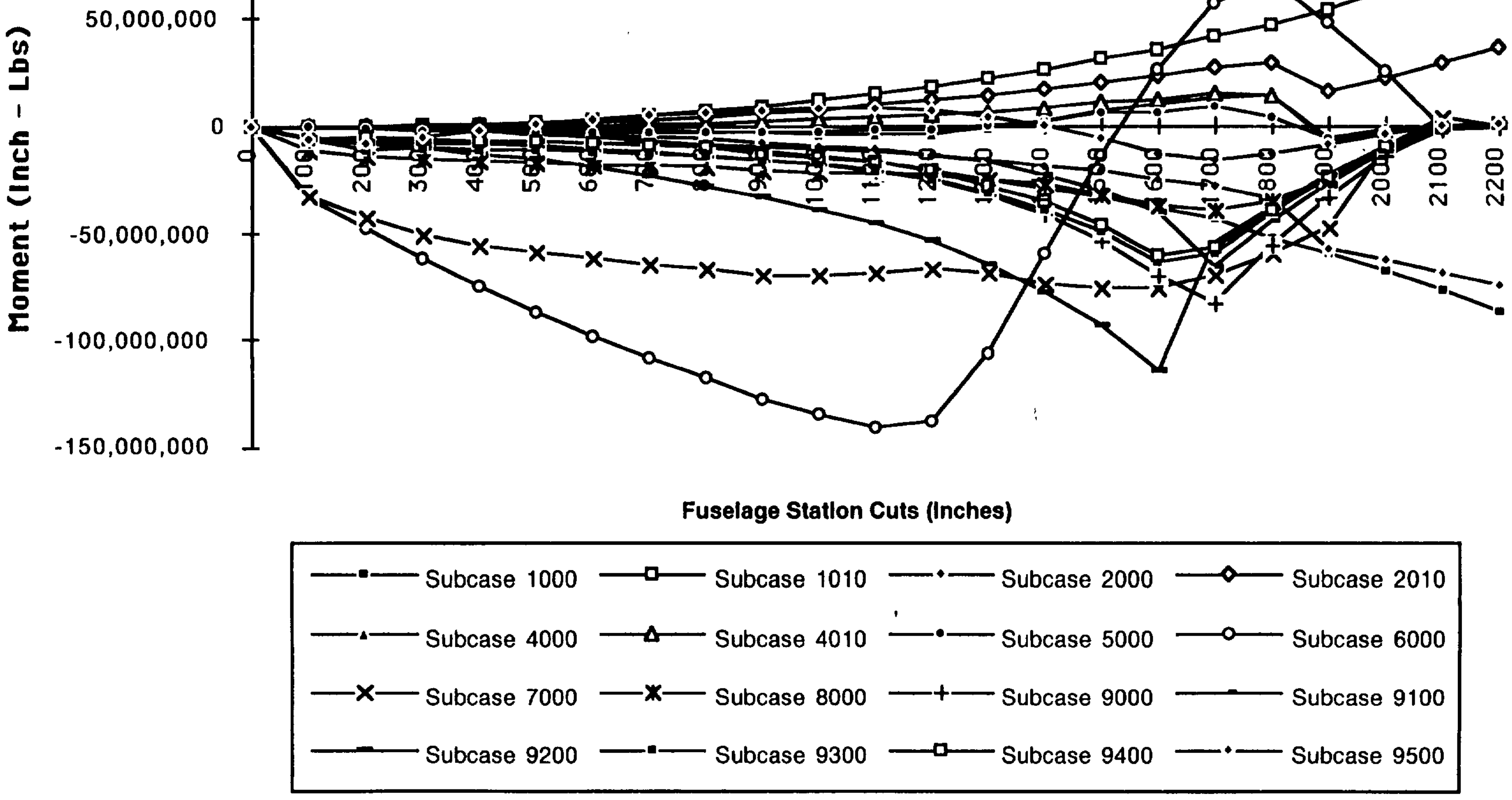
Configuration 4B - Pitching Moment

SSTO



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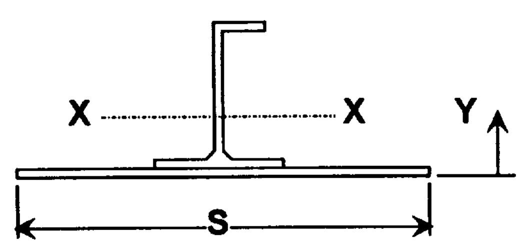
Composite LH Tank, Intertank and Wing Structural Analysis

Analysis Methodology for Composite Stiffened Skin

REUSABLE CRYOTANKS

Develop Stiffener Crippling Capability



$\frac{b}{t}\left[\frac{Fcu^{x}}{(ExEy)^{1/2}}\right]^{1/2}$ = Parameter For IML Cap/Web Crippling

Find $K = F^{cc} / Fx^{cu}$ From Non-Dimensional Crippling Curves

$F^{cc} = KFx^{cu}$ Each Stiffener Element

$F^{cc}stiffener = \frac{\sum b_n t_n F_n^{cc}}{\sum b_n t_n}$ For Stiffener Crippling Failure

Calculate Composite Cross Sectional Properties

$$\overline{Y} = \frac{\sum ExAY}{\sum ExA}; ExIxx = \sum ExAY^2 + \sum ExIo - \sum ExA(\overline{Y})^2$$

Calculate Element Stresses and Margins of Safety for Compression Load, Nx(lbs/in)

$$f_n^c = \frac{NxSExn}{\sum ExA}$$

$$M.S.Strength = \frac{F_x^{c} u_n}{f_n^c} - 1$$

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Analysis Methodology for Composite Stiffened Skin (Cont.)

REUSABLE CRYOTANKS

Calculate Column Slenderness Ratio for Frame Spacing, L (in.)

$L' = L/\sqrt{c}$, Where c (assumed) = 1.4 For Semi-Pinned Ends

$$\rho = \left[\frac{ExIxx}{ExA}\right]^{1/2}$$

Check Mode of Failure

for $L'/\rho > \dfrac{4\pi\, Ex_{stiff}}{Ex_{stiff} + 4\, F^{cc}_{stiff}}$ Section Will Fail By Stiffener Crippling

for $L'/\rho < \dfrac{4\pi\, Ex_{stiff}}{Ex_{stiff} + 4\, F^{cc}_{stiff}}$ Section Will Fail By Elastic Buckling or Interaction Between Buckling and Crippling

Calculate Fco and Fcr

$$Fco = F^{cc}_{stiffener}\left[1 + \frac{4\, F^{cc}_{stiffener}}{Ex_{stiffener}}\right]$$

$Fcr = Fco\left[1 - \dfrac{Fco(L'/\rho)^2}{4\pi^2\, Ex_{stiffener}}\right]$ If $Fcr < \dfrac{Fco}{2}$ Section Will Buckle As An Elastic Long Column (Euler),

$$\approx Fcr = \frac{\pi^2\, Ex_{stiffener}}{(L'/\rho)^2}$$

Analysis Methodology for Composite Stiffened Skin (Cont.)

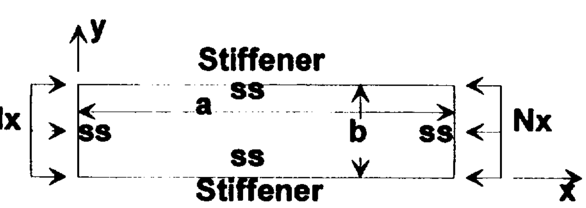
REUSABLE CRYOTANKS

Calculate Stiffener Crippling/Section Buckling Margin of Safety

$$M.S._{crippling/\,buckling} = \frac{Fcr}{f^{c}_{stiff}} -$$

Check Tank Wall (skin) Buckling Between Stiffeners

$$\text{For } a/b \to \infty, N_{Xcr} = 2\frac{\pi^2}{b^2}\left[\sqrt{D_{11}D_{22}} + D_{12} + 2D_{66}\right]$$



Where D_{11}, D_{22}, D_{12}, D_{66} = Skin Laminate Bending Stiffness

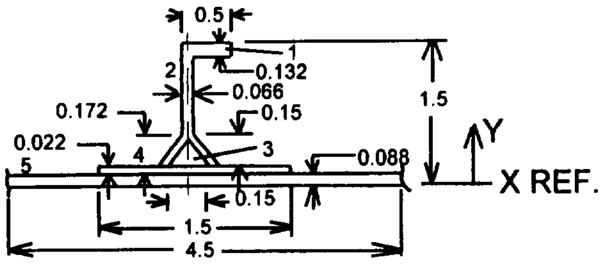
Calculate Skin Buckling Margin of Safety

$$M.S._{skin\ buckling} = \frac{N_{Xcr}}{N_X} - 1$$

Example Calculation - Composite Stiffened Skin

REUSABLE CRYOTANKS

Stiffener/Skin Cross Section



LAMINATE CONFIGURATIONS

1,2,4 (70 / 30 / 0); $E_x = 15.2x10^6$; $F_x^{cu} = 115.0\ KSI\ (-423F)$

3 (100 / 0 / 0); $E_x = 20.4x10^6$; $F_x^{cu} = 222.0\ KSI\ (-423F)$

5 (±54.7); $E_x = 3.0x10^6$; $F_x^{cu} = 30.4\ KSI\ (-423F)$

CROSS SECTIONAL PROPERTIES

ELE	Ex (msi)	b (in.)	t (in.)	A (in.2)	ExA	Y (in.)	ExAY	ExAY2*	ExIo
1	15.2	0.5	0.132	0.066	1.0032	1.434	1.438589	2.062936	0.001457
2	15.2	0.066	1.258	0.083028	1.262026	0.739	0.932637	0.689219	0.166436
3	20.4	--	--	0.01125	0.2295	0.16	0.03672	0.005875	--
4	15.2	1.5	0.022	0.033	0.5016	0.099	0.049658	0.004916	0.0002
5	3	4.5	0.088	0.396	1.188	0.044	0.052272	0.0023	0.000766
SUM				0.589278	4.184326		2.509876	2.765246	0.168679

$$\overline{Y} = \frac{(2.509876)}{(4.184326)} = 0.599828 \quad \text{in.(from REF.)}$$

$$EI_{xx} = (2.765245) + (0.168679) - (4.184326)(0.599828)^2 = 1.428431x10^6 lbs.\text{–}in.^2$$

$$E_xA = 4.184326\ lbs.$$

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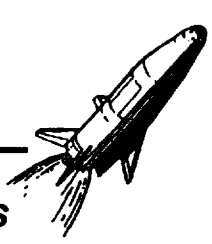
Example Calculation - Composite Stiffened Skin (cont.)



REUSABLE CRYOTANKS

Develop Stiffener Crippling Capability

Element 1 Stiffener IML Cap

b/t = (0.50)/(0.132) = 3.79 (1EF)

Calculate -

$$b/t\left[\frac{F_X^{CU}}{(E_X E_Y)^{1/2}}\right]^{1/2} = 3.79\left\{\frac{(115000)}{[(15.2x10^6)(3.0x10^6)]^{1/2}}\right\}^{1/2}$$

$$= 0.494 \qquad (E_Y = 3.0x10^6)$$

$F^{CC} / F_X^{CU} = 0.98$ (for parameter = 0.494) 1EF

$F_{CC_1} = (0.98)(115000) = 112700$psi (ref. revised reference to Rockwell Bluebook)

Calculate Element Stresses

Given: Nx=2422 lbs./in/ (limit) Compression
Nx(ULT.) = 1.4 x N_x(limit)

Elements 1,2,4 (Stiffener):

$$f_C(LIMIT) = \frac{(2422)(15.2)(4.5)}{(4.184326)} = 39592psi$$

Example Calculation - Composite Stiffened Skin (cont.)

Element 2 Stiffener Web

b/t = (1.086)/(0.066) = 16.45 (NEF)

Calculate -

$$(16.45)\{(0.130499)\} = 2.15$$

$F^{CC} / F_X^{CU} = 0.46$ (for parameter = 2.15) NEF

$F^{CC}_2 = (0.46)(115000) = 52900$psi

$$F^{CC}_{1+2} = \frac{(0.5)(0.132)(112700) + (1.086)(0.066)(52900)}{(0.5)(0.132) + (1.086)(0.066)}$$

$= 81560$psi (Stiffener)

Element 3 (Filler):

$$f_{C(LIMIT)} = \frac{(2422)(20.4)(4.5)}{(4.184326)} = 53136 psi$$

Element 5 (Tank Skin):

$$f_{C(LIMIT)} = \frac{(2422)(3.0)(4.5)}{(4.184326)} = 7814 psi$$

Calculate Element Strength Margins

$$M.S._{1,2,4} = \frac{(115000)}{(1.4)(39592)} - 1 = +HIGH$$

$$M.S._{3} = \frac{(222000)}{(1.4)(53136)} - 1 = +HIGH$$

$$M.S._{5} = \frac{(30400)}{(1.4)(7814)} - 1 = +HIGH$$

Example Calculation - Composite Stiffened Skin (cont.)

REUSABLE CRYOTANKS

Calculate Slenderness Ratio

$$L' = \frac{L}{\sqrt{C}}$$

L = Frame Spacing = 29.5 in. (per SSD FEM)

C=1 Assume pinned ends

$$= L(29.5in.)$$

$$\rho = \left[\frac{E_x I}{E_x A}\right]^{1/2} = \left[\frac{1.428431}{4.184326}\right]^{1/2} = 0.584274in.$$

$$L'/\rho = (29.5)/(0.584274) = 50.49$$

Check Mode of Failure

$$\frac{4\pi E_{XStiff.}}{E_{XStiff.} + 4F_{CCStiff.}} = \frac{(4)(\pi)(15.2x10^6)}{(15.2x10^6) + (4)(81560)} = 12.3$$

$$L'/\rho = 50.49 > 12.3$$

Therefore section will fail by elastic buckling or interaction between buckling and crippling.

Calculate Fco

$$F_{CO} = F_{CCStiff.}\left(1 + \frac{4F_{CCStiff.}}{E_{XStiff.}}\right)$$

$$= (81560)\left[1 + \frac{4(81560)}{(15.2x10^6)}\right]$$

$$= 83310psi$$

Example Calculation - Composite Stiffened Skin (cont.)

Calculate Johnson-Euler Crippling Allowable

$$F_{CR} = F_{CO}\left(1 - \frac{F_{CO}(L'/P)^2}{4\pi^2 E_{X\,Stiff.}}\right)$$

$$= (83310)\left[(1) - \frac{(83310)(50.49)^2}{(4)(\pi^2)(15.2x10^6)}\right] = 53824 psi$$

$$F_{CR} = 53824 > \frac{F_{CO}}{2} = \frac{(83310)}{(2)} = 41655$$

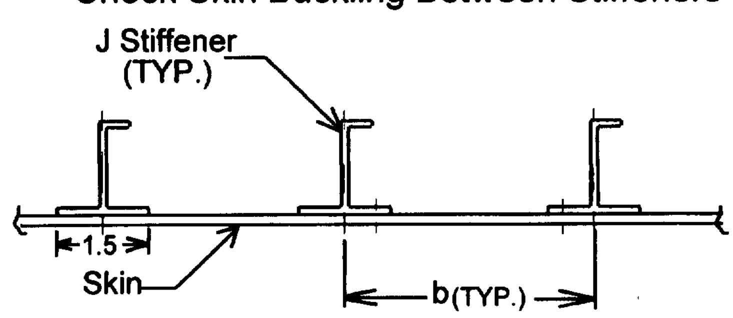
Therefore, the Johnson-Euler calculation applies (rather than the Euler allowable).

Calculate Margin of Safety (Stability)

$$M.S._{1,2} = \frac{(53824)}{(1.4)(39592)} - 1 = -0.02$$

Example Calculation - Composite Stiffened Skin (cont.)

Check Skin Buckling Between Stiffeners

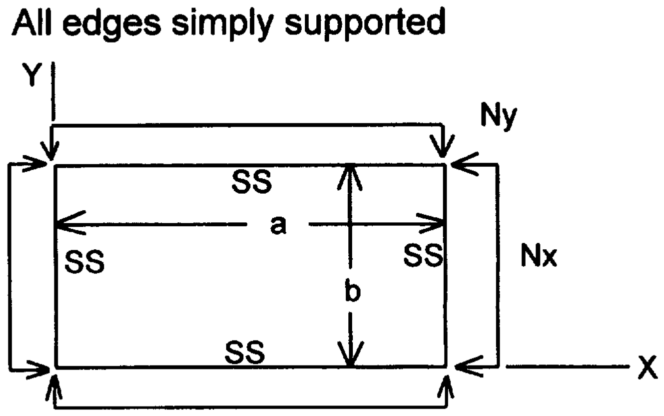


b(TYP.) = 4.5 IN.

Orthotropic Plates (D16=D26=0)

Compression

All edges simply supported



If N_y or N_x = 0 and a/b or b/a

$$N_{X_{CR}} = 2\frac{\pi^2}{b^2}\left[\sqrt{D_{11}D_{22}} + D_{12} + 2D_{66}\right]$$

For the (±54.7) laminate skin,

$$\left.\begin{aligned} D_{11} &= 282.66 \\ D_{22} &= 618.62 \\ D_{12} &= 265.15 \\ D_{66} &= 282.55 \end{aligned}\right\} \text{PSANMOD program run } 10-27-94$$

$$N_{X_{CR}} = \frac{(2)(\pi^2)}{(4.5)^2}\{[(282.66)(618.62)]^{1/2} + (265.15) + (2)(282.55)\}$$
$$= 1216 lbs./in.$$
$$F_{X_{CR}} = (1216)/(0.088) = 13818 psi$$

Calculate Margin of Safety (Skin Stability)

$$M.S._5 = \frac{(13818)}{(1.4)(7814)} - 1 = +0.26$$

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Optimization Analysis for Honeycomb Sandwich Cylinders

Axial Compression (Isotropic Facesheets)

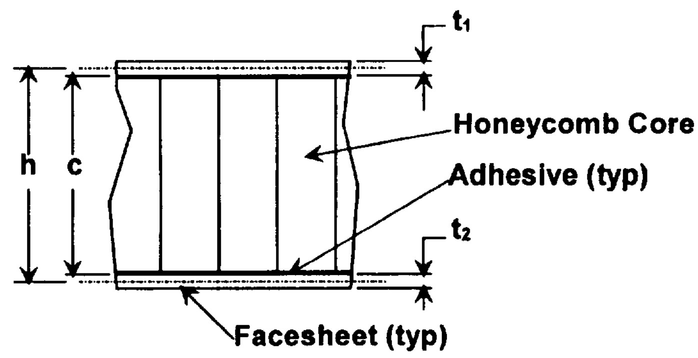
Design Allowable Buckling Stress:

$$\sigma_{cr} / \eta = \gamma_1 C_c E \frac{h}{r} \frac{2\sqrt{t_1 t_2}}{\sqrt{1-\mu^2}\,(t_1 + t_2)}$$

$for\ t_1 = t_2 = t_f$

$$\sigma_{cr} / \eta = \gamma_1 C_c E \frac{h}{R} \frac{1}{\sqrt{1-\mu^2}}$$

(Equal Facesheets, R = Radius of Cylinder)



For the region of application $C_c = (1 - V_c)\ for\ \frac{G_{xz}}{G_{\theta z}} \le 1$

$and\ 0.95\,(1 - V_c)\ for\ \frac{G_{xz}}{G_{\theta z}} \ge 1.$

With $V_c = \frac{cEt_f}{2\sqrt{1-\mu^2} hRG_{xz}}, \frac{c}{h} \approx 1$ and using $C_c = (1 - V_c)$,

$$\sigma_{cr} / \eta \frac{\gamma_1}{\sqrt{1-\mu^2}} \left[1 - \frac{Et_f}{2RG_{xz}\sqrt{1-\mu^2}} \right] E \frac{h}{R}. \qquad \gamma_1 = \text{Correction Factor for } R / \rho$$

Introducing the load requirement and assuming $N_x = 2t_f \sigma_{cr}\ (\eta = 1)$,

$$\frac{N_x}{2t_f} = \sigma_{cr} = \frac{\gamma_1}{\sqrt{1-\mu^2}} \left[1 - \frac{Et_f}{2RG_{xz}\sqrt{1-\mu^2}} \right] E \frac{h}{r}$$

Optimization Analysis for Honeycomb Sandwich Cylinders

Rearranging and solving for sandwich facing centroid dimension,

$$h = \frac{N_x R\sqrt{1-\mu^2}}{\gamma_1\left[2t_f - \frac{E t_f^2}{R G_{xz}\sqrt{1-\mu^2}}\right]E}.$$

Weight per square foot of a honeycomb sandwich is calculated by:

$$W_s = 2t_f\rho_f + W_{adh} + \rho_c\frac{h}{12}$$ ρ_f *and* ρ_c = facesheet and core densities

Substituting for h,

$$W_s = 2t_f\rho_f + W_{adh} + \frac{\rho_c}{12}\,\frac{N_x R\sqrt{1-\mu^2}}{\gamma_1\left[2t_f - \frac{E t_f^2}{R G_{xz}\sqrt{1-\mu^2}}\right]E}.$$

For known facesheet, core and adhesive materials the unknowns are t_f, γ_1 and G_{xz}.

Optimization is achieved by iteration of facesheet and core (adhesive weight is constant).

Optimization Analysis for Honeycomb Sandwich Cylinders

Check for stability to preclude intracell buckling and facesheet wrinkling.

$\sigma_{cr} / \eta = K_L \dfrac{E}{1 - \mu^2}$ where K_L is a function of t_f / s $(s =$ honeycomb cell size$)$

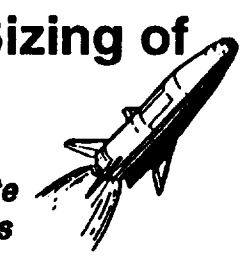
$\sigma_{cr} / \eta = K_W \sqrt[3]{E E_c G_c}$ where E_c = flatwise compression modulus of core

G_c = shear modulus of core

$K_W = 0.43$

Note: These isotropic formulas will be used for trade study sizing. They will be modified for orthotropic properties for detail design.

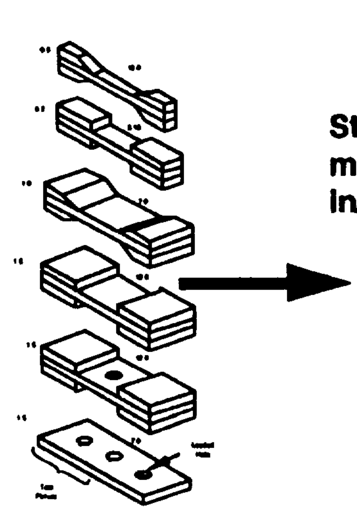
Established Gr/BMI Design Allowables Permit Preliminary Sizing of Intertank, Wing and Tail Primary Structures



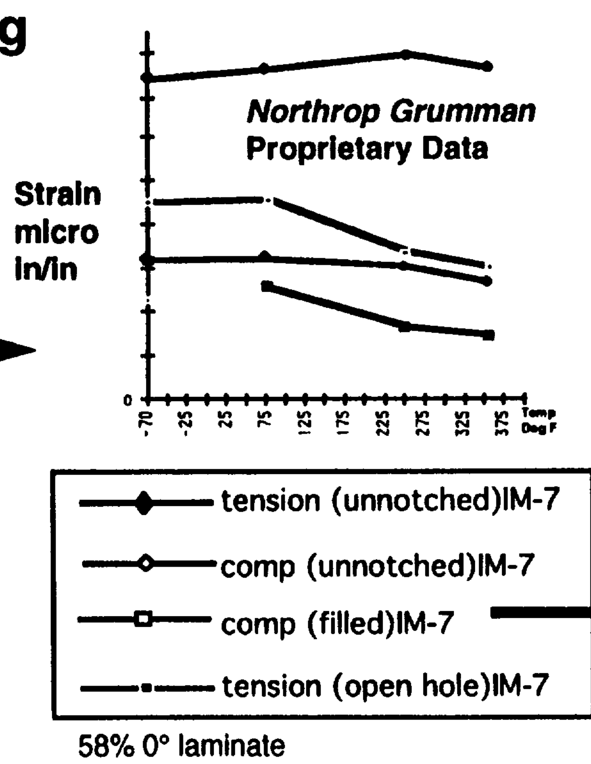
Composite Structures

Northrop Grumman Established Allowables Database

- **Multi batch laminae and laminate testing**



- **Design Allowables**



- **Sizing Analysis**

example:

•<u>Laminate Strength Check</u>:

Margin of Safety M.S.= $\varepsilon_{allowable}/\varepsilon_{applied}-1$

$\varepsilon_{applied} = N_x/2tE_x$ for sandwich

N_x- Load applied
E_x- Modulus
t- each face sheet thickness

<u>Design Allowables size structure</u>

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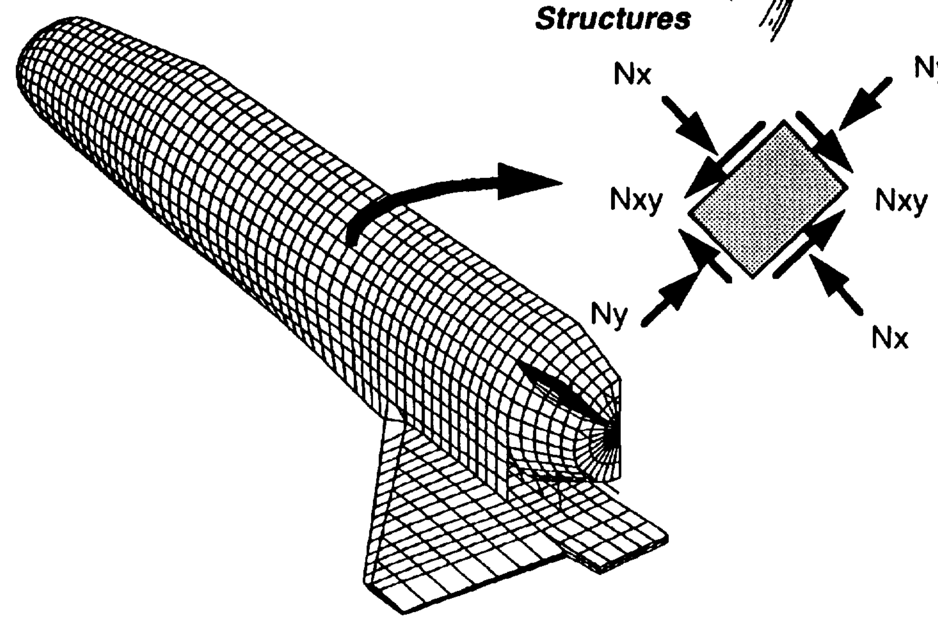
Competiton Sensitive

Intertank Skin Sizing Analysis Examines Strength, Wrinkling, and Stability Failure Criteria

Composite Structures

Finite Element Model Forces



• **Laminate Strength Check**:

Margin of Safety M.S.= $\varepsilon_{allowable}/\varepsilon_{applied} - 1$

$\varepsilon_{applied} = N_x/2tE_x$ for sandwich

N_x- Load applied
E_x- Modulus
t- each face sheet thickness
$\varepsilon_{allowable}$ = from established design allowables ($\varepsilon_{filled\ hole\ compression}$)

• **Face Sheet Wrinkling Check:**

$F_{wr} = [.82\{E_c t/(E_x E_y)^{1/2}\, t_c\}^{1/2}\ (E_x E_y)^{1/2}]/(1+.64k)$

M.S.= $(F_{wr}/f_{applied})-1$

where $k = (\delta E_c)/t_c F_c$ and $\delta = .0052$
Reference: MIL-HDBK-23A, pg 3-4, eq. 3:6

• **Shell Stability Check:**

$F_c = ((kK(E_x E_y)^{1/2})/\lambda^{1/2})(h/r)$

M.S.= $(F_c/f_{applied})-1$

Reference: MIL-HDBK-23A, pg 12-3, eq 12:3a

k- reduction factor, cylinder
K- theoretical buckling coefficient, core

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COMPETITION SENSITIVE

Intertank Frame Sizing Analysis Examines Strength, Stability Failure Criteria

Composite Structures

Finite Element Model Forces

• **Frame Stiffness Requirement**
(prevent general instability of skin)

$EI_{Fmin} = 6.48x10^{-5}(N_{xskin})(4\pi R^4)/L_{frame\ spacing}$

reference Rockwell Structural Design Manual 9.42.06

• **Laminate Strength Check:**

$f = Mc/I + P/A$
$\varepsilon_{max} = f/E_x$

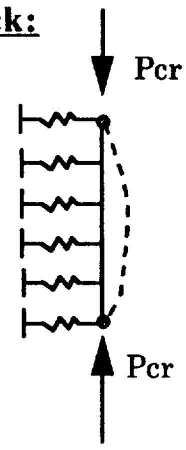
Margin of Safety $M.S. = \varepsilon_{allowable}/\varepsilon_{max} - 1$

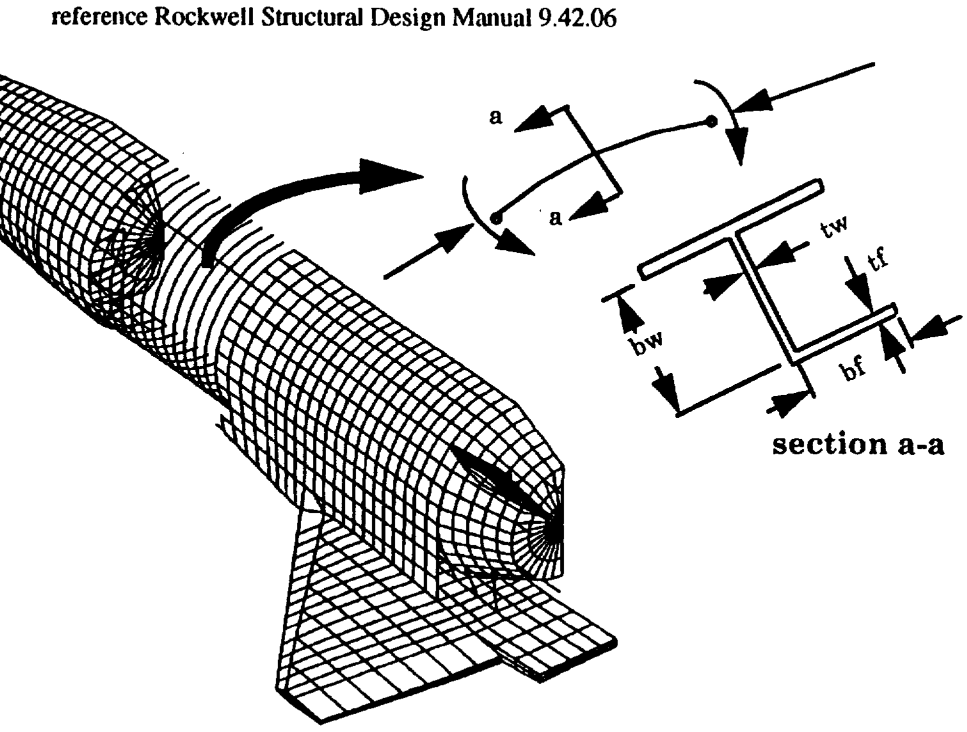
• **Inner Flange Stability Check:**

$P_{cr} = 2(KEI)^{1/2}$

$K = 3EI_w/b_w^3 = E(t_w/b_w)^3/4$
$I = t_f (b_f)^3/12$
$E = (E_xE_y)^{1/2}$ for flange

$M.S. = (P_{cr}/P_f) - 1$





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COMPETITION SENSITIVE

Intertank Frame Sizing Analysis Examines Crippling Failure Criteria

Composite Structures

- **Crippling Check** (Reference Northrop Grumman PBUCKL-5 analysis code)

General Equation

$\varepsilon_{cs} = \alpha\varepsilon_{cr}(\varepsilon_{cu}/\varepsilon_{cr})^{\beta}$

ε_{cs}- crippling strain, ε_{cr} - initial buckling strain

ε_{cu}- compression ultimate laminate

α, β - coefficents developed from test data

For flange

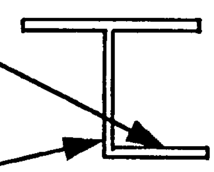
$\varepsilon_{cs\,flange} = .45\varepsilon_{cr}(\varepsilon_{cu}/\varepsilon_{cr})^{.73}$

where $\varepsilon_{cr} = (12D_{66}/b^2tE_x)+(4\pi^2D_{11}/L^2tE_x)$

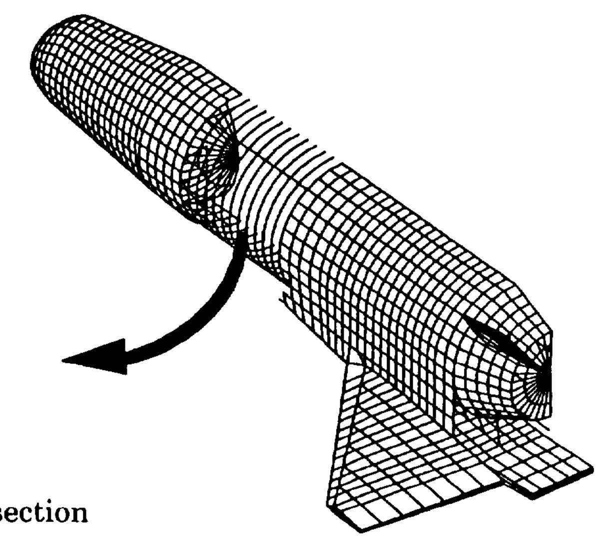
M.S.= $\varepsilon_{cs\,flange}/\varepsilon_{app}$-1

For web

$\varepsilon_{cs\,web} = .57\varepsilon_{cr}(\varepsilon_{cu}/\varepsilon_{cr})^{.48}$



frame cross section (conceptual)



Finite Element Model

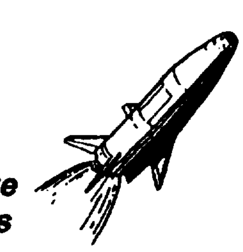
where $\varepsilon_{cr} = (2\pi^2/bt^2E_x)[(D_{11}D_{22})^{1/2}+D_{12}+2D_{66}]$

if $\varepsilon_{cs\,web} < \varepsilon_{cs\,flange}$ then

$\varepsilon_{cs}=[(E_xA_{flange})/(E_xA_{flange}+E_xA_{web})](\varepsilon_{cs\,flange}-\varepsilon_{cs\,web}) + \varepsilon_{cs\,web}$

M.S.= $\varepsilon_{cs}/\varepsilon_{app}$-1

Intertank Longeron Sizing Analysis Examines Strength and Buckling Failure Criteria



- **Laminate Strength Check**

$f = Mc/I + P/A$
$\varepsilon_{max} = f/E$
$M.S. = \varepsilon_{allowable}/\varepsilon_{max} - 1$

- **Beam Column**
(approx. for preliminary sizing, ref. Northrop Grumman Structural Design Manual section 414)

Euler Buckling
$\varepsilon_{cr} = (C\pi^2 EI)/EAL^2$

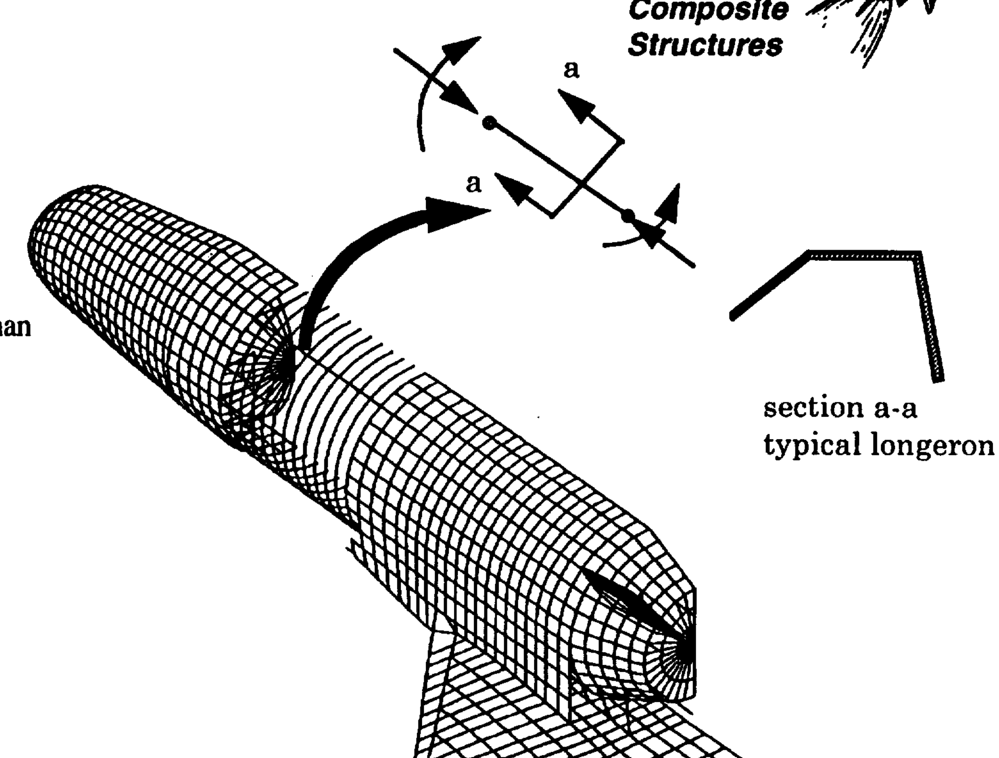
EI- bending stiffness
EA-equivalent axial stiffness
L-longeron length
C-end fixity coefficient

Bending

$f = Mc/I$, $\varepsilon = f/E_x$

$R_c = \varepsilon_c/\varepsilon_{cr}$
$R_b = \varepsilon_b/[\varepsilon_{allow}(1-(\varepsilon_c/\varepsilon_{cr}))]$

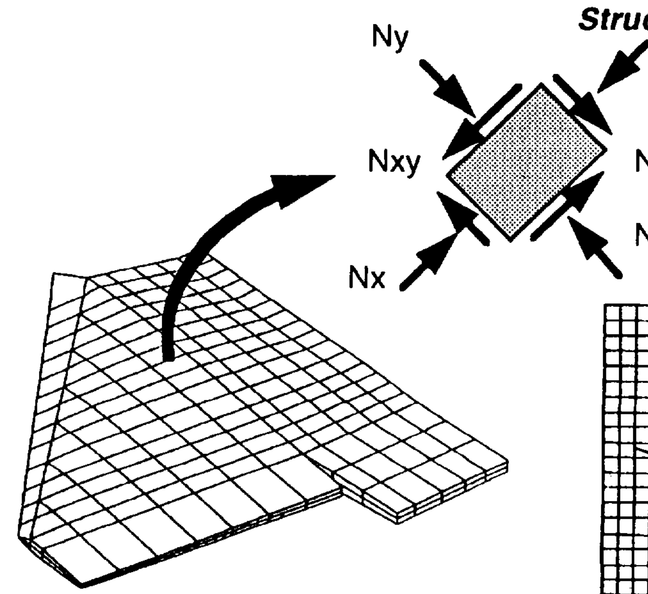
$M.S. = (1/(R_c+R_b)) - 1$



Wing Skin Sizing Analysis Examines Strength, Wrinkling, and Stability Failure Criteria

Composite Structures

Finite Element Model Forces



- **Laminate Strength Check:**

Margin of Safety $M.S. = \varepsilon_{allowable}/\varepsilon_{applied} - 1$

$\varepsilon_{applied} = N_x/2tE_x$ for sandwich

N_x - Load applied
E_x - Modulus
t- each face sheet thickness
$\varepsilon_{allowable}$ = from established design allowables

- **Face Sheet Wrinkling Check:**

$F_{wr} = [.82\{E_c t/(E_x E_y)^{1/2} t_c\}^{1/2} (E_x E_y)^{1/2}]/(1+.64k)$

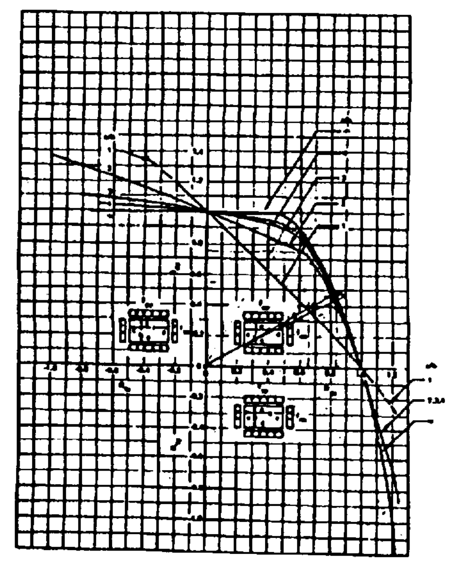
$M.S. = (F_{wr}/f_{applied}) - 1$

where $k = (\delta E_c)/t_c F_c$ and $\delta = .0052$
Reference: MIL-HDBK-23A, pg 3-4, eq. 3:6

- **Skin Stability Check:**

$F_c = (\pi^2 K/4)(h/b)^2((E_x E_y)^{1/2}/\lambda)$
$R_x = f_{cx}/F_{cx},\ R_y = f_{cy}/F_{cy}$

$M.S. = R'_x/R_x - 1 \longleftarrow R'_x$

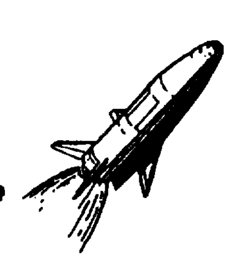


Interaction curves

References: MIL-HDBK-23A ppg 5-2, eq. 5:2a
Northrop Grumman Structural Design Manual pg 301.6.4

Wing Spar/Rib Webs are sized for Strength and Stability

Composite Structures



Finite Element Model Forces

- **Laminate Strength Check**

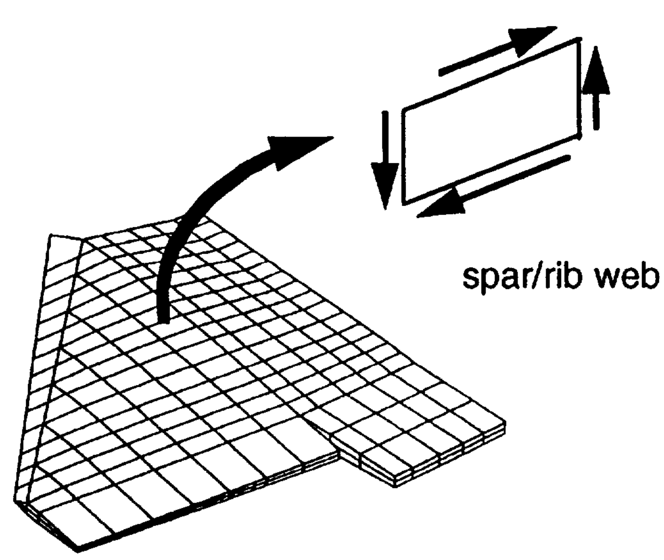
Margin of Safety M.S.= $\varepsilon_{allowable}/\varepsilon_{applied} - 1$

- **Web Stability Check**

$F_s = (\pi^2 K/4)(h/b)^2 ((E_x E_y)^{1/2} / \lambda)$

ref. MIL-HDBK-23A, pg 6-2, Eq.6:2a

M.S.= $(F_s/f_s) - 1$



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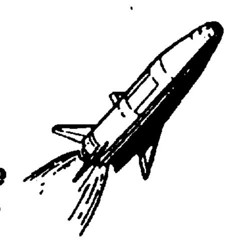
COMPETITION SENSITIVE

Wing Analysis includes Examination of Fastened and Bonded Joints



Fastened Joint

- Calculate maximum load per fastener, P, using grid point forces
- Calculate allowable load per fastener using analysis code BJSFM, Pallow (ref. Northrop Grumman Structural Design Manual section 402.6)

$M.S.=(P_{allow} / P)-1$

Bonded Joint

- Calculate maximum shear flow

$$q=P/L$$

- Calculate allowable shear flow

$$q_{allow} = F_{su} (W_{eff})$$

$$M.S.= (q_{allow} / q) -1$$